

DOE/ER/10250--T7

DE86 004246

ANNUAL REPORT 1984

10th ANNIVERSARY SPECIAL EDITION

HAWAII NATURAL ENERGY INSTITUTE

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

University of Hawaii at Manoa
Honolulu, Hawaii

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

PL

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Special recognition and thanks to Nancy Nishikawa and Mike Tamaru for their assistance in the completion of this report.

In addition, HNEI would like to gratefully acknowledge the contributions of Mary Kamiya, whose help made possible the fruition of this special ten-year edition of the HNEI Annual Report. Her many talents and the hours which she dedicated to assist HNEI are immeasurable and most appreciated.



EXECUTIVE CHAMBERS
HONOLULU

GEORGE R. ARIYOSHI
GOVERNOR



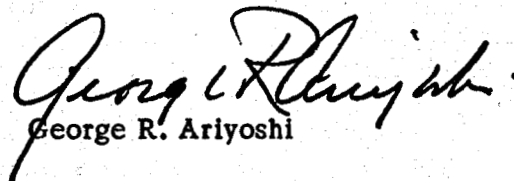
MESSAGE FROM GOVERNOR GEORGE R. ARIYOSHI

It is with a great sense of pride that I extend my congratulations to all of those who have worked so diligently over the past decade to make the Hawaii Natural Energy Institute a leader in the state's efforts toward greater energy self-sufficiency.

Ten years ago, at the time the Hawaii Natural Energy Institute was created by an act of the Legislature, we were in a precarious position. We were suffering from the effects of the OPEC oil embargo, with short supplies and rapidly-escalating prices. The challenge became clear: We had to reduce our dependency on imported petroleum through conservation and the development of our indigenous renewable energy resources.

The Hawaii Natural Energy Institute, working with other government agencies and private industry, has been a leader in the research and development of Hawaii's abundant geothermal, ocean thermal, biomass, solar, wind, and hydroelectric energy resources. Great strides have been made in the advancement of these technologies. The Hawaii Natural Energy Institute will most certainly play a leading role in formulating Hawaii's energy future by further research and development on our present technologies, as well as assessing and developing those which will sustain us in the next century.

We can all be pleased and encouraged by the accomplishments of the Hawaii Natural Energy Institute. Building on the achievements of the past decade, I am confident we will be able to utilize Hawaii's plentiful natural energy resources for greater economic independence and increased energy self-sufficiency for the people of the state.


George R. Ariyoshi



DEPARTMENT OF PLANNING AND ECONOMIC DEVELOPMENT

KAMAMALU BUILDING, 250 SOUTH KING ST, HONOLULU, HAWAII
MAILING ADDRESS: P.O. BOX 2359, HONOLULU, HAWAII 96804 • TELEX: 7430250 HIDPED

GEORGE R. ARIYOSHI
GOVERNOR

KENT M. KEITH
DIRECTOR

MURRAY E. TOWILL
DEPUTY DIRECTOR

LINDA KAPUNIAI ROSEHILL
DEPUTY DIRECTOR

DIVISIONS

BUSINESS AND INDUSTRY DEVELOPMENT DIVISION
ENERGY DIVISION
335 Merchant St., Room 110, Honolulu, Hawaii 96813
FOREIGN-TRADE ZONE DIVISION
Pier 2, Honolulu, Hawaii 96813
LAND USE DIVISION
PLANNING DIVISION
RESEARCH AND ECONOMIC ANALYSIS DIVISION

OFFICES

DIRECTOR'S OFFICE
ADMINISTRATIVE SERVICES OFFICE
INFORMATION OFFICE

MESSAGE FROM STATE ENERGY RESOURCES COORDINATOR

As State Energy Resources Coordinator, I would like to congratulate HNEI on its Tenth Anniversary! HNEI has played a major role in researching and promoting awareness of renewable energy resources.

During the past decade, HNEI has helped bring us closer to developing the technologies required for energy self-sufficiency in electricity. During the next decade, HNEI can help bring us closer to developing the technologies required to produce transportation fuels from indigenous resources.

The stabilization of the world oil price over the past few years has slowed the development of energy alternatives by the private sector. Further, the Reagan Administration has reduced funding for non-nuclear energy programs. State activities have thus become even more important than when HNEI was established.

It is the policy of the State Administration to continue its strong support for the research and development of renewable energy, even while oil prices are lower and supplies seemingly are adequate. We believe that the introduction of alternate energy technology is a good thing, for several reasons. First, oil supplies will run out eventually. Second, the existing oil supplies could be freed for better uses, such as petrochemicals for making plastics, instead of burning oil for energy. Third, the greater the share of our energy supply we produce locally, the more protected we are from future energy supply interruptions. Fourth, developing indigenous energy industries would improve our net balance of trade and boost the local economy.

Perhaps the most important aspect of renewable energy is that it is a significant economic development opportunity for the State of Hawaii. One of our major State economic development strategies is to substitute local production for the goods we must now import. Oil is our largest single import--in 1983 we spent \$1.3 billion on imported oil and petroleum products, equalling approximately 10 percent of our Gross State Product. A domestic renewable energy industry would not only provide us with a stable, abundant, low-polluting indigenous energy supply, but would also provide the benefits of increased employment and additional tax revenues. Few economic development opportunities are as promising as this one.

The State Administration believes that we are in a useful "reprieve" period. It is now that new technologies should be researched, designed, tested, and installed. When prices rise again, these new technologies could be in place, or only a step away.

There are several aspects to the State's energy program. We have plans and projects for energy conservation, and for development of renewable energy to produce electricity. Our biggest single problem, however, is producing liquid fuels from indigenous sources. Transportation fuels account for nearly two-thirds of the State's energy consumption, but we are just beginning to develop a long-term plan and programs to produce transportation fuels. We are greatly encouraged by the work at the Hawaii Natural Energy Institute regarding fuels from biomass and hydrogen. The work to develop liquid and gaseous fuels can best be conducted through the kind of specialized university research programs which HNEI is already sponsoring.

DPED and HNEI must work closely together in preparing for our energy future. HNEI has the research and development role, and DPED, commercialization. Our State's success in developing renewable energy in the long term thus depends on the effectiveness of both DPED and HNEI. We are partners, responsible for sequential stages in the development process. We at DPED are proud of this partnership. We look forward to working together with HNEI in the coming years.



Kent M. Keith

Kent M. Keith



University of Hawaii at Manoa

Office of the Chancellor
Hawaii Hall 103 • 2500 Campus Road
Honolulu, Hawaii 96822

MEMORANDUM

To: Dr. Patrick Takahashi
Director
Hawaii Natural Energy Institute

I am delighted to have the opportunity to congratulate the leadership and staff of the Hawaii Natural Energy Institute on your Tenth Anniversary. During this ten-year period we have seen the State of Hawaii evolve from being a site of testing and demonstration projects in natural energy to become a world leader in developing renewable energy technologies. This is in great part due to your leadership.

We at the University of Hawaii are also pleased that the Hawaii Natural Energy Institute has found an appropriate place among the organized research units on campus and that a permanent director for the institute has been selected. Your institute is a credit to the University, and we look forward to great things from you in the next decade.



David Morrison
Acting Vice Chancellor for
Research and Graduate Education



DIRECTOR'S MESSAGE

The Hawaii State Legislature created HNEI in 1974 through Act 235, which cited Hawaii's "total dependence for energy on imported fuel" and "our vulnerability to dislocation in the global energy market," and further stated that "there are few places in the world so generously endowed with natural energy: geothermal, solar radiation, ocean temperature differential, wind...all non-polluting sources." HNEI was established to "coordinate and undertake the development of non-polluting natural energy sources for Hawaii....to provide the needed visibility, focus, and encouragement for energy related activities into viable energy systems that will:

1. diminish Hawaii's total dependence on imported fossil fuels,
2. meet the state's increasing energy demands with little or no environmental degradation, and
3. contribute to the technology base for finding solutions to the national and global energy shortage."

A decade later the economic impact of energy has indeed become significant. The annual cost of crude oil imports to Hawaii has increased by a factor of ten since the early '70s. In 1970 Hawaii's agriculture revenues were almost four times our crude oil import bill—last year the situation reversed itself, as Hawaii now pays twice as much for its oil imports compared to the annual produce income from the entire agricultural industry. In reality, the situation is even worse, as the annual combined gasoline, jet fuel and electricity bill exceeds \$2 billion, or almost three times our agriculture revenues. In short, although energy prices have stabilized, energy has become an important part of Hawaii's daily economy, with an unreliable supply line that could change overnight through any number of worldwide events.

While one might wonder what the State has done to remedy this untenable situation, since we import about as much oil today as we did in 1973, and appear to remain just as vulnerable to an energy crisis as we did then, a look at our renewable energy development program can be illuminating. At the time of the Arab oil embargo ten years ago Hawaii had no real alternatives to oil and sugar cane. Today:

1. Geothermal energy drives a 3 MW power plant at Puna, and several commercial efforts are underway on the Big Island.
2. Solar energy conversion is making an important contribution today in the form of solar water heating and shows promise through photovoltaics and solar thermal options.
3. Biomass is currently Hawaii's number two fuel for providing electricity and could provide for all of Hawaii's ground transportation fuels of tomorrow.

4. Wind energy conversion is near commercialization on a large scale in Hawaii and various non-utility applications are being developed by HNEI.
5. Ocean thermal energy conversion has advanced to the point where we are the world's leading center for R&D.

Whether the stimulation was basic research or sponsorship of leading-edge workshops and conferences, these developments would not have advanced as rapidly had it not been for HNEI and the University of Hawaii working in close partnership with the Department of Planning and Economic Development (DPED) and other state agencies, county governments, and the private sector.

From early in the state energy program the University of Hawaii was assigned the research and development role, while the DPED took responsibility for energy conservation, emergency planning, and those technologies nearing the marketplace. There is close collaboration between DPED and HNEI in carrying on a united state-wide program.

During the past decade, HNEI has supported 152 distinct projects involving 75 faculty members. A ten year summary follows:

	Number of Projects	Federal/Private	State	Total
Biomass	28	\$1,521,656	\$511,726	\$2,033,382
Geothermal	28	309,841	975,270	1,285,111
Ocean	29	637,296	489,524	1,126,820
Solar	18	1,312,127	799,689	2,111,816
Wind	18	259,284	658,422	917,706
Hydrogen	9	75,056	50,000	125,056
Other	22	591,317	425,282	1,016,599
Totals	152	\$4,706,577	\$3,909,913	\$8,616,490

Over the next few years focus will be placed on those renewable energy technologies where Hawaii offers a unique advantage or has a special need. Certainly, ocean energy, geothermal applications and biofuels research, to be primarily conducted at our unique laboratories—Natural Energy Laboratory of Hawaii, Puna Geothermal Research Facility, and Renewable Resources Research Laboratory—will be of high priority.

In addition, HNEI has signed cooperative agreements or has initiated joint research programs with the Florida Solar Energy Center, New Mexico Solar Energy Institute, Solar Energy Research Institute, Renewable Energy Institute and the Pacific International Center for High Technology Research. We are taking a leading role in developing an international hydrogen from renewable energy program involving scientists from Japan, Canada, and the European community. Also, I serve as the program director of the Fellows in Renewable Energy Engineering Program, which has received \$413,500 in commitments from the private sector. Geothermal and ocean energy specialists will be selected in 1985.

Hawaii by itself cannot support all the R&D necessary to attain energy independence. We can, however, spur development, catalyze interest, form partnerships, leverage funds, and establish certain steeples of excellence.

The energy picture of 21st Century Hawaii looks a lot brighter compared to the days when HNEI was created. We have established a base from which will be derived by the Year 2000, the technologies that generate our electricity and power our transportation options. However, we must wisely take advantage of this fortunate reprieve period of energy price stability to continue an active program which can insure for greater energy self-sufficiency.

Patrick K. Takahashi
Patrick K. Takahashi
Director



Honolulu Star-Bulletin

Published by Gannett Pacific Corporation

CHINN HO, CHAIRMAN

ALEXANDER ATHERTON, PRESIDENT

PHILIP T. GIALANELLA, PUBLISHER

JOHN E. SIMONDS
Executive Editor

A. A. SMYSER
Contributing Editor

William Cox, Managing Editor; Cynthia Oi, Assistant Managing Editor, News; Susan Yin, Today Editor; Bill Kwan, Sports Editor; James Blankenship, News Editor; Charles E. Frankel and Carl Zimmerman, Assistant Editors, Editorial Page.

Published at 605 Kapiolani Boulevard Honolulu, Hawaii 96813

A-14

Wednesday, March 28, 1984

Renewable Energy Research in Hawaii

The Hawaii Natural Energy Institute at the University of Hawaii is celebrating its 10th anniversary and has put out a special issue of its newsletter focusing on what's been done in renewable energy research and development.

The issue relates how the state Legislature created the institute in reaction to the 1973-74 oil crisis following the Arab embargo. Hawaii was particularly vulnerable because of its overwhelming dependence on oil. Its only other sources of energy were sugar cane waste for burning as boiler fuel to generate electricity and a small amount of hydroelectric power.

The Legislature said the institute was to "coordinate and undertake the development of non-polluting natural energy sources for Hawaii." It said that "there are few places in the world so generously endowed with natural energy: geothermal, solar radiation, ocean temperature differential, wind . . . all potential non-polluting power sources."

Much has been done in the past 10 years, and the institute takes justifiable pride in its achievements. The institute has supported 231 projects with a total budget of \$7.5 million, half of these funds coming from external sources.

The newsletter says that hydroelectric power, biomass energy (thermal and electrical) from sugar cane waste, solar water heating and heat pumps, some small photovoltaic installations, the three-megawatt geothermal power plant on the Big Island, and more than 300 wind machines will produce about 8 percent of Hawaii's total energy requirement this year. This will save at least \$110 million in oil imports.

Patrick K. Takahashi, acting director of the institute, said that it "is maturing into an academic research center on the verge of attaining excellence in many of these renewable energy technologies."

But he also said that while the past 10 years have been marked with achievement, the next decade will be crucial. The newsletter says that during the past year the oil cost to Hawaii's economy has increased 10 fold, from a little over \$100 million before 1973 to well over \$1 billion a year today.

"Our energy problem, in fact, is far more serious than a decade ago," it says. Despite the research done and money spent, large-scale commercial implementation is not yet cost-effective in most cases.

The Hawaii Natural Energy Institute has made a good start. But there is much yet to be done, by the institute, by all units of government, by industry and the general public before Hawaii's energy problems are eased.



TABLE OF CONTENTS

Message from the Governor.....	iii
Message from the State Energy Resources Coordinator.....	iv
Message from the Acting Vice Chancellor for Research and Graduate Education	vi
Director's Message.....	vii
HNEI Personnel.....	1
FREE Program Board of Advisors.....	5
Energy Research Advisory Board (ERAB).....	6
Energy Self-Sufficiency Coordinating Committee.....	8
A HISTORY OF THE HAWAII NATURAL ENERGY INSTITUTE 1974-1984	9
INTRODUCTION.....	11
BIOMASS ENERGY RESEARCH.....	23
GEOTHERMAL ENERGY RESEARCH.....	33
OCEAN ENERGY RESEARCH	41
SOLAR ENERGY RESEARCH	51
WIND ENERGY RESEARCH.....	61
OTHER RENEWABLE ENERGY RESEARCH	71
TEN YEARS OF HNEI ACTIVITIES.....	81
HNEI RESEARCH AND DEVELOPMENT PROJECT SUMMARIES 1983-1984	87
BIOMASS ENERGY RESEARCH.....	89
Energy Tree Farm R&D	90
James L. Brewbaker	
Flash Pyrolysis of Biomass Derived Model Compounds Dissolved in a Supercritical Solvent.....	91
Michael J. Antal, Jr.	

Fuel Source Potential of Hawaii's Forest.	93
Michael J. Antal, Jr.	
Stone and Webster Economic Feasibility Study of Biomass to Alcohol Plants	94
Patrick K. Takahashi	
Combustion Properties of Biomass Pyrolysis Products	95
Joel Fox	
Physiological and Biochemical Determinants of Biomass Productivity in Fast-Growing Nitrogen-Fixing Trees	96
Douglas J. C. Friend/Harry Y. Yamamoto	
Algal Production Raceway Project	97
Edward Laws	
GEOTHERMAL ENERGY RESEARCH.	99
Scaling and Corrosion Experiments with Geothermal Heat Exchangers.	100
Bill H. Chen	
Seismic and Thermal Properties of Hawaiian Basalts	102
Murli H. Manghnani	
Inert Gas Abundance Patterns as Geothermal Tracers	103
Donald M. Thomas/John Naughton	
Hydrology, Chemistry, and Microbiology of Geothermal Systems on the Submarine Rift Zones of the Hawaiian Chain	104
Gary M. McMurtry	
Investigation of the Sodium/Lithium Geothermometer for Hawaiian Geothermal Systems	106
Eric H. DeCarlo/Donald M. Thomas	
Numerical Modeling of Groundwater in the East Rift Zone of Kilauea, Hawaii.	107
David Epp	
Shallow Magma Chambers and Geothermal Potential of the Haleakala Southwest Rift Zone.	108
John M. Sinton	
Biological Abatement of Hydrogen Sulfide During Geothermal Energy Production	110
David M. Karl	
OCEAN ENERGY RESEARCH	111
Open-Cycle Evaporator Experiment	112
Jorn Larsen-Basse	

Electrochemical Measurements of Corrosion and Biofouling Films on Simulated OTEC Heat Exchangers	114
Bruce E. Liebert	
Nitrogenous Products of OTEC Chlorination and Their Potential Effects on OTEC Aquaculture.	115
Francis J. Sansone	
Dynamic Positioning of a Floating OTEC Plant Using Environmental Forces	117
John P. Craven	
Potential Effect of OTEC Waste Water on Natural Phytoplankton Assemblages	118
Satoru Taguchi	
Breaking Wave Forces on OTEC Pipes	119
Robert A. Grace	
Hydrodynamic Loading on Shelf-Mounted OTEC Plant Structures	121
Theodore T. Lee	
SOLAR ENERGY RESEARCH	123
High-Temperature Solar Concentrator Absorber for Hydrogen and Water	124
James Holm-Kennedy	
Solar Energy Laboratory on the Roof of Holmes Hall	126
Michael J. Antal, Jr.	
Cleansing Techniques for Immiscible Solar Ponds	128
Karl H. Bathen	
Hawaiian Solar Radiation Measurement and Development of Statistical Parameters	129
Paul C. Ekern	
Measuring and Describing Direct Insolation on Molokai	131
George D. Curtis	
Rooftop Photovoltaic Systems on Lived-In Units in Hawaii	133
Patrick K. Takahashi	
Pacific Island Solar Monitoring Program	135
Patrick K. Takahashi	
Photovoltaic Power System at Hawaii Institute of Marine Biology	136
Patrick K. Takahashi	
WIND ENERGY RESEARCH	137
Wind Energy Battery Storage Project	138
Patrick K. Takahashi	

Development of a Wind Forecasting Program for Wind Farms.	139
Thomas A. Schroeder	
HYDROGEN RESEARCH	141
Electrode/Electrolyte Interfaces for Hydrogen or Methanol Production	142
William Pong	
Characterization of Hydrides for Hydrogen Storage	143
Bruce E. Liebert	
Characterization of Metal Hydrides Suitable for Hydrogen Storage or Methanol-Hydrogen Conversion	145
Philip W. Payne	
Interaction of Hydrogen and Deuterium with Transition Metals and Their Alloys at High Pressures	146
Shiv K. Sharma	
Thermal Decomposition of Zinc Sulfate Related to Solar-Thermochemical Hydrogen Production	148
Michael J. Antal, Jr./Ali Tabatabaie-Raissi	
Characterization of Metal Hydrides at High Pressures and Temperatures.....	150
Li-Chung Ming	
OTHER RENEWABLE ENERGY RESEARCH	151
Electric Vehicle Project.....	152
Patrick K. Takahashi	
Environmental Quality Studies	154
Sanford M. Siegel/Barbara Z. Siegel	
Hawaii Deep Water Cable Program: Electrical Cable Corrosion Testing	155
Jorn Larsen-Basse	
Graduate Student Assistantships	156
OTHER HNEI PROGRAMS	159
EDUCATIONAL PROGRAMS	161
Conferences/Workshops	161
Lectures	166
Graduate Programs at UHM.....	168
INTERNATIONAL/INTERAGENCY COOPERATIVE PROGRAMS	169
HNEI PUBLICATIONS	171



PERSONNEL

Under the directorship of Dr. Patrick Takahashi, HNEI's core support and technical staff provide support services for energy-related research projects and programs at the University. The bulk of the research administered by the Institute has been conducted by faculty representing the university system. In addition, Dr. Michael Antal, Coral Industries Professor of Renewable Energy Resources, supervises a small staff in his Renewable Resources Research Laboratory which was established jointly by the College of Engineering and the Hawaii Natural Energy Institute.

CORE STAFF

Patrick K. Takahashi, Ph.D., Director
Sidney H. Browne, Ph.D., Assistant to the Director
D. Richard Neill, B.S., M.Div., Program Coordinator
Lois H. Sato, B.Ed., Administrative Assistant
Arthur S. Seki, M.S., Associate Researcher
Valerie M. Ziobro, B.A., Technical Editor/Writer
Gail N. Yonamine, B.B.A., Account Clerk
Sandra M. Yonemura, Secretary
Ellen K. Kubota, Clerk Typist
Linda M. Ome, B.S., Project Secretary
James Bac, B.B.A., Research Assistant

TECHNICAL SUPPORT STAFF

George D. Curtis, B.S., Technical Coordinator
Byron H. Aufer, M.S., Systems Engineer
Brian H. Ito, B.S., Computer Programmer
Sueji Yano, B.S.A.E., Technician

HNEI SABBATICAL FELLOW

T.W. Fraser Russell, Ph.D., Director of the Institute of Energy Conversion and
Allan P. Colburn Professor of Chemical Engineering, University of Delaware

RENEWABLE RESOURCES RESEARCH LABORATORY

Michael J. Antal, Jr., Ph.D., Coral Industries Professor of Renewable Energy Resources
Ali Tabatabaie-Raissi, Ph.D., Assistant Researcher
William S.L. Mok, M.S., Scientific Instrument Designer
Jibendra C. Roy, Ph.D., Assistant Researcher
Constance B. Kawamoto, B.A., Secretary

GRADUATE ASSISTANTS

Carlos P. DeAlmeida
Sallie F. Edmunds
Ravi Narayan
Sundaresh Ramayya
Bruce O. Tsutsui
Daniel D. Weeks

STUDENT ASSISTANTS

Dean Arashiro
Clarke Bright
Sophie Chiu
Bruce Gareth Chen
Tracie Higashi
Colin Hugo
Darlyne Inouye

Robert Phan
Sheri Ann Sakamoto
Glen Sakima
Betty Simmerer
Patti Takahashi
Brant Yamamoto



Sandra Yonemura with Patrick Takahashi



Linda Ome



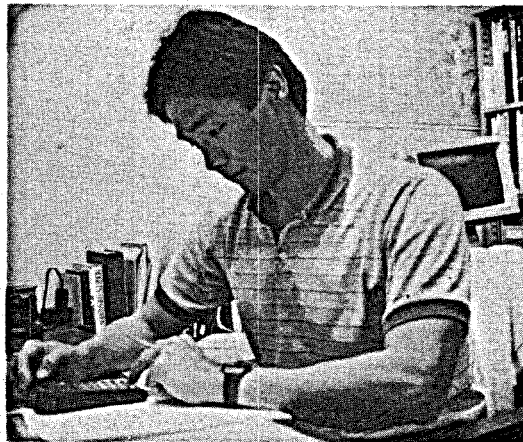
Gail Yonamine



Sueji Yano



Michael Antal and Connie Kawamoto



Arthur Seki



**Patrick Takahashi with ORA
Fiscal Officer, Wilfred Li**



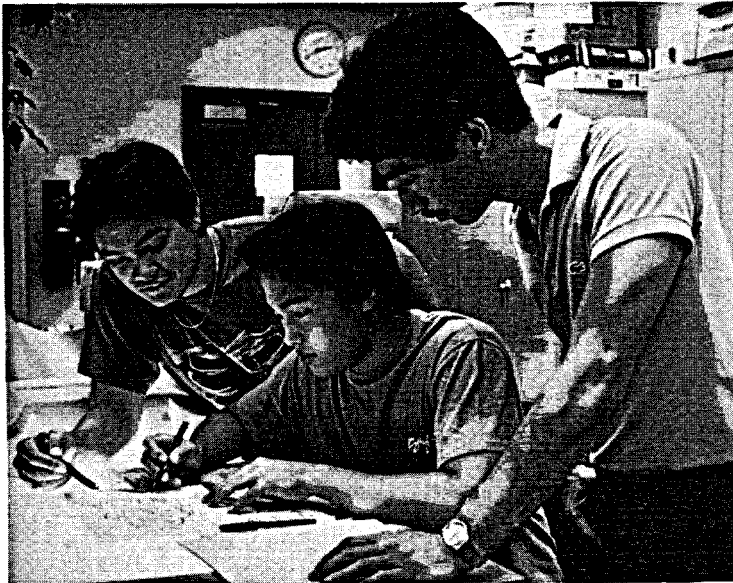
Brian Ito and Byron Auker



Sidney Browne with Lois Sato



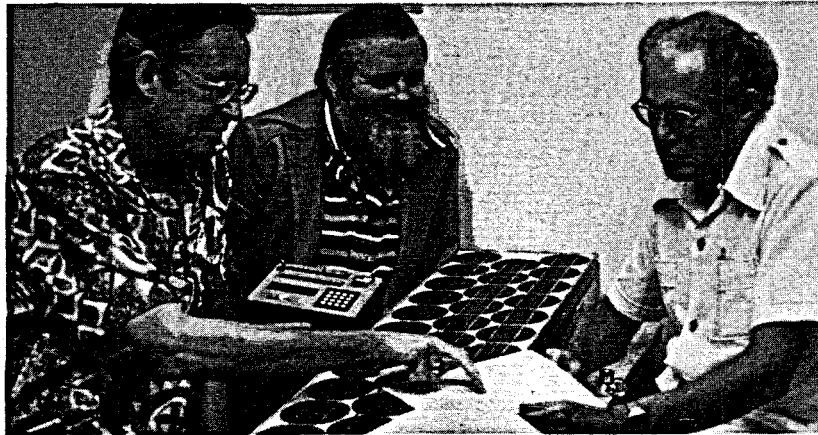
Valerie Ziobro



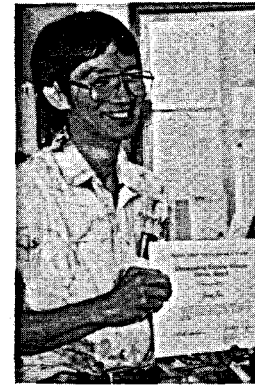
Left to right: Clarke Bright, Brant Yamamoto and Gareth Chen



Carlos DeAlmeida



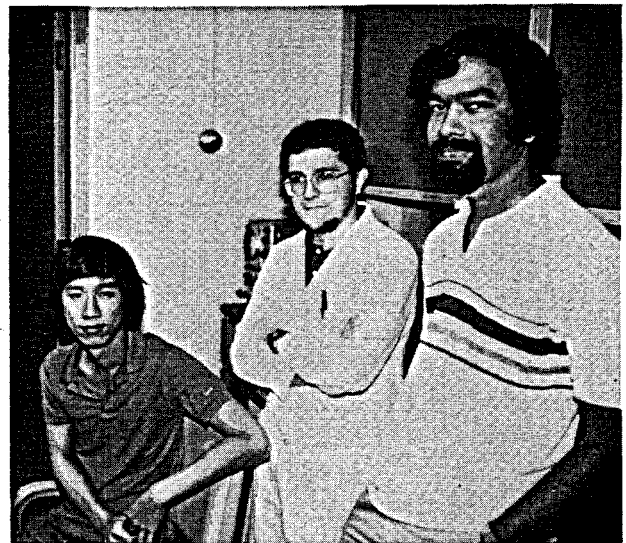
Left to right: George Curtis, Dick Neill and Fraser Russell



James Bac



Ellen Kubota



Left to right: William Mok, Ali Tabatabaie-Raissi and Jiben Roy

FREE PROGRAM BOARD OF ADVISORS

The Spark Matsunaga Fellows in Renewable Energy Engineering (FREE) Program matching University funds with corporate and foundation support, was initiated to build a renewable energy program of academic and research excellence at the University of Hawaii. The program is provided broad guidance by the following distinguished Board of Advisors:

The Honorable Spark M. Matsunaga, Chairman
United States Senate

Donald T. Beldock
Chairman of the Board
Basic Resources Corp., Inc.

David L. Block
Director
Florida Solar Energy Center

Frank W. Bradley
Vice President
Chevron, U.S.A.

James Caldwell
President
ARCO Solar Industries

Melvin Calvin
Professor of Chemistry
University of California

Robert T. Hayden
Executive Director
Renewable Energy Institute

Allan R. Hoffman
Executive Director
National Academy of Sciences

Harold M. Hubbard
Director
Solar Energy Research Institute

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

Lawrence T. Papay
Senior Vice President
Southern California Edison Company

C. Dudley Pratt, Jr.
President
Hawaiian Electric Industries, Inc.

John W. Shupe
Director, Pacific Site Office
U.S. Department of Energy

Thomas E. Stelson
Vice President for Research
Georgia Institute of Technology

Patrick K. Takahashi
Director
Hawaii Natural Energy Institute

Bob J. Tharpe
General Manager, Advanced Energy
Programs Department
General Electric Company

Byron J. Washom
President
ADVANCO

Kenneth F. Weaver
Science Editor
National Geographic

Paul C. Yuen
Dean, College of Engineering
University of Hawaii

Harry S. Zwibel
Director
New Mexico Solar Energy Institute

ENERGY RESEARCH ADVISORY BOARD (ERAB)

The University Energy Research Advisory Board (UHM ERAB) has assisted HNEI in reviewing proposals submitted by faculty members. ERAB's membership includes research directors and members from both the public and private sectors to enhance the University's responsiveness to the business community and local government agencies. ERAB members who evaluated and selected energy projects supported by HNEI in FY 1984 and FY 1985 are listed below.

University of Hawaii Members:

Pfiflip Helfrich, Director
Hawaii Institute of Marine Biology

Charles E. Helsley, Director
Hawaii Institute of Geophysics

Noel P. Kefford, Dean
College of Tropical Agriculture and Human Resources

Patrick K. Takahashi, Director and Chairman of the Board
Hawaii Natural Energy Institute

State and County Officials:

Michael J. Chun, Director
Department of Public Works, City and County of Honolulu

Ralph N. Masuda, Deputy Director
Department of Planning, County of Maui

Takeshi Yoshihara, Program Administrator
Division of Energy, State Department of Planning & Economic Development

Business Community:

Richard L. O'Connell, Vice President, Engineering
Hawaiian Electric Company

Joseph A. Pelletier, President
Pacific Resources, Inc.

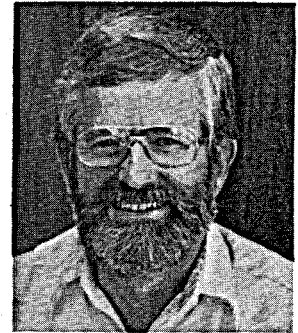
George E. St. John, President
Amfac Energy, Inc.



Michael Chun



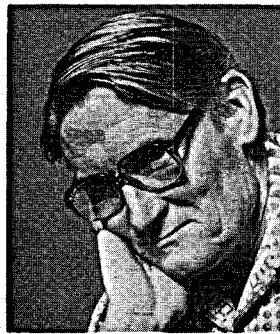
Philip Helfrich



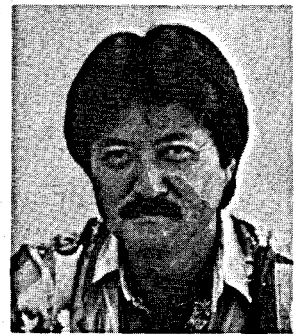
Charles Helsley



**E. Chipman Higgins, HECO
Past ERAB member**



Noel Kefford



Ralph Masuda



Richard O'Connell



Joseph Pelletier

Photo: Wiley-Honolulu



George St. John

Photo: Wiley-Honolulu



Patrick Takahashi



Takeshi Yoshihara

ENERGY SELF-SUFFICIENCY COORDINATING COMMITTEE

The HNEI State/County ESS Coordinating Committee is composed of state and county government officials as well as representatives from the private sector. The purpose of this committee is to coordinate energy self-sufficiency planning efforts and recommend priorities for state and county energy programs.

Members include the following:

Jerry A. Allen
Vice President, Real Estate Marketing
C. Brewer & Company, Ltd.

William W. Blanchard
Energy Coordinator
County of Kauai

Kelvin L. Kai
Manager, Transmission and Distribution
Kauai Electric Division
Citizens Utilities Company

H. Stuart Kearns, Jr.
Director, Department of Research and Development
County of Hawaii

Kent M. Keith
Director
Department of Planning and Economic Development

Chew Lun Lau
Environmental Engineer, Department of Public Works
City & County of Honolulu

Edward J. Lui
General Manager
PRI Energy Systems, Inc.

Ralph N. Masuda
Deputy Director, Planning Department
County of Maui

John W. Shupe
Director, Pacific Site Office
U.S. Department of Energy

Patrick K. Takahashi
Director
Hawaii Natural Energy Institute

Takeshi Yoshihara
Energy Program Administrator, Energy Division
Department of Planning and Economic Development



TEN-YEAR HISTORY

INTRODUCTION

ORIGINS

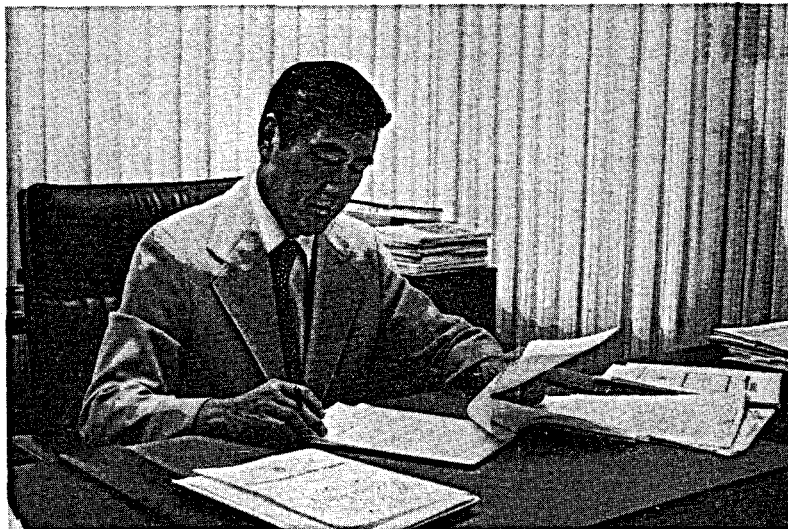
Alternative energy research and development in Hawaii has gained considerable momentum over the past decade. A few isolated research projects in geothermal, ocean thermal, and biomass energy were conducted at the University of Hawaii in the late 1960s and early 1970s when it was generally agreed that the idea of replacing imported oil with indigenous renewable resources made philosophical sense. However, it took the economic crunch of two oil crises and their attendant gasoline lines to spur concerted activity in energy planning and research.

The 1974 Hawaii State Legislature enacted energy-related bills that not only established the Hawaii Natural Energy Institute (HNEI), but also created the Natural Energy Laboratory of Hawaii (NELH); the State Program for Energy Planning and Conservation, later to become the Energy Division of the Department of Planning and Economic Development (DPED); and the position of State Energy Resources Coordinator. Governor Ariyoshi appointed then director of DPED, Hideto Kono, to the concurrent position of energy resources coordinator. Until 1983, Kono was instrumental in focusing the attention of both the executive and legislative branches on energy conservation and alternative energy development. Strong support for energy programs has continued under the current director and energy resources coordinator, Kent Keith.

Act 235 established HNEI as a research unit at the University of Hawaii-Manoa (UHM) with an appropriation of \$55,000 in FY 1974-75 to develop recommendations for the administrative structure and operational guidelines of the institute. The bill noted that "there are few places in the world so generously endowed with natural energy: geothermal, solar radiation, ocean temperature differential, wind...all potential non-polluting power sources....Development of these energy sources would help to diminish Hawaii's total dependence on imported fossil fuels, to meet the State's increasing energy demands with little or no environmental degradation, and to contribute to the technology base for finding solutions to the national and global energy shortage."



The two past directors of HNEI, John Shupe (left) and Paul Yuen.



Hideto Kono (above), former State Energy Resources Coordinator and DPED Director; and present ERC and DPED Director, Kent Keith (below).



HNEI, under the initial leadership of John Shupe, provided direction and assistance to ongoing energy-related research throughout the UH system, and encouraged new programs and research on alternatives to seaborne petroleum. A university-wide energy planning committee and a broadly based policy committee developed organizational and operational guidelines.

One of HNEI's first tasks was to organize and provide staff support for the Governor's Committee on Alternate Energy Sources, an offshoot of the Advisory Task Force on Energy Policy which had been appointed by Governor Ariyoshi in 1974. The committee analyzed the potential of ten alternative energy sources to contribute to Hawaii's energy requirements, and made recommendations on research and development that should be undertaken in Hawaii and the level of state support needed. HNEI, in cooperation with DPED, published a report on the committee's findings which rated geothermal, wind, solar, OTEC, and solid waste/bioconversion as "highly significant" for Hawaii's future. It is interesting to note that these research areas remain in the forefront today. Table 1 summarizes this early assessment.

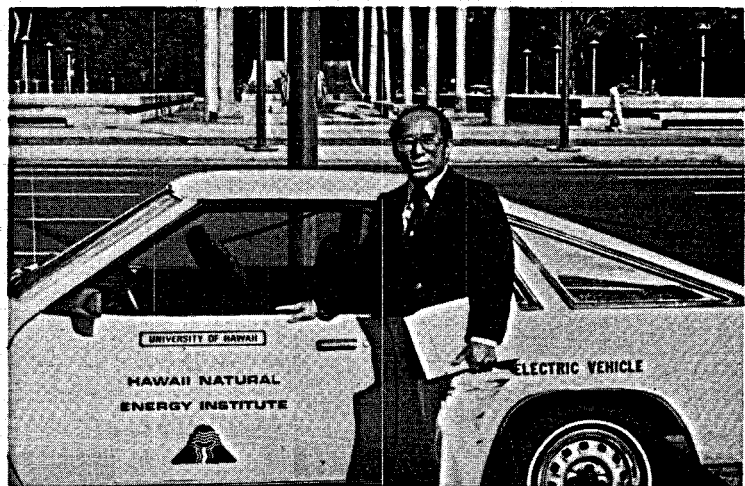
Table 1
SUMMARY OF ALTERNATE ENERGY SOURCES FOR HAWAII

Alternate Energy Source	State of Technology Development	Potential* Importance to Hawaii	Time Scale for Demonstration of Concept	Recommended State Interest in Adaptive Technology	Recommended State Interest in R&D Support
Solid Waste (Urban Ore)	Intermediate	Moderate	1980	High	Low
Bioconversion Bagasse	Advanced	Significant	Currently Active	Moderate	Moderate
Other (Kelp, Algae, etc.)	Exploratory	Slight	Mid-80's	Moderate	Moderate
Hydroelectric Power	Advanced	Moderate	Currently Active	High	Low
Wind	Intermediate	Significant	Late 70's	High	High
Geothermal Energy	Intermediate	Significant	1980	High	High
Solar Collectors					
Heating & Cooling	Intermediate	Significant	Immediate	High	Moderate
Electrical Generation	Exploratory	Significant	1990	High	Low
OTEC	Exploratory	Significant	Mid-80's	High	High
Waves, Tides, Ocean Currents, Osmosis	Exploratory	Slight	Late 70's	Moderate	Low
Coal					
Granular	Advanced	Moderate	1990	Moderate	Low
Liquifaction & Gasification	Exploratory	Significant	Mid-80's	High	Low
Nuclear Power (Fission Reactor)	Advanced	?	?	Low	Low

*Potential importance to Hawaii from the present to Year 2000. *Slight*—can provide less than 2 percent of the State's electrical energy requirements; *Moderate*—from 2 to 10 percent; and *Significant*—10 percent or more of the total electrical energy demand.

Source: "Alternate Energy Sources for Hawaii, 1975," HNEI/DPED, February 1975.

The report, well-received at the national as well as state level, was submitted to the 1975 State Legislature, which responded by funding natural energy research and development at \$1.9 million for the following two years. The impetus for this legislation and for subsequent funding of HNEI activities by the legislature came from State Senator T. C. Yim, then chairman of the Senate Energy and Natural Resources Committee. During his tenure, Yim rallied interest in energy issues by drawing up *A Comprehensive Energy Program for Hawaii* for the 1978 Legislature and by conducting workshops on energy research, development, and demonstration for fellow legislators and their staffs with the assistance of his aide, D. Richard Neill.



Senator T. C. Yim with HNEI electric vehicle.

As a follow-up to the report, DPED and HNEI cosponsored a Workshop on Alternate Energy Sources for Hawaii in May 1975 that incorporated the best current thinking of some of the nation's top energy scientists, engineers, and planners into programs for Hawaii's energy future. The workshop provided national visibility to the variety and abundance of natural energy resources in the state. It also served to initiate HNEI's involvement with the Energy Research and Development Administration (ERDA) and other federal agencies, and with the private sector and local governmental entities, both from Hawaii and the mainland.

These early committees came to a consensus on two major propositions: (1) that there were no short-term substitutes for oil that could reduce Hawaii's oil dependence in the next ten years, and (2) a number of indigenous and renewable resources showed excellent potential for meeting a significant percentage of Hawaii's future energy needs. The Governor's committee concluded that for these alternatives to play a vital role in achieving an appropriate level of energy self-sufficiency, the state must continue to establish policy, programs, and institutions to verify the technical, environmental, and economic feasibility of its natural energy resources.

Two important roles for HNEI emerged from this early work. First, a program of resource assessment and monitoring was begun to determine which resources would best serve as alternatives to oil. Second, HNEI would coordinate the R&D interactions among government, private industry, the utilities, community organizations, and individuals in order to maximize cooperation and funding. In turn, DPED accepted responsibility for overall energy policy, energy conservation, and assistance to new technologies nearing the marketplace.

An excellent example of this cooperative interaction is the Hawaii Geothermal Project (HGP) led by the University of Hawaii. The 1972 State Legislature appropriated \$200,000 for geothermal research, contingent on federal matching funds. Initial external funds were provided through a \$252,000 grant from the National Science Foundation (NSF) in FY 1973. Over the next eight years, research, development, and demonstration support from NSF, ERDA, and its successor, the U.S. Department of Energy (USDOE), exceeded \$11 million for the project. State and private sources, primarily the Hawaiian Electric Company, provided additional funds. The well and power plant would eventually result in total funding exceeding \$14 million, 73 percent of which was provided by non-state sources. An additional \$20 million has been spent by the private sector in follow-up geothermal exploratory drilling and development activities. HNEI supported 28 geothermal research projects in the 1974-84 period with funds totalling \$1,285,111, of which \$306,841 were from federal sources.

The early organizational work by the Governor's Committee and the Workshop on Alternate Energy Sources showed Hawaii leaders what resources were available. The next task would be to quantify these resources and to determine the quality and quantity of energy they could provide. Much of the very basic research and the expensive and risky developmental work would be left to the federal government, other national governments, and the private sector. HNEI's emphasis would be to develop an information base on renewable energy resources, to show the private sector and the federal government that Hawaii could be the natural energy laboratory for the nation, and to initiate and cultivate start-up programs that would stimulate desired development and ultimately leverage external funds.

HNEI BEGINS RESEARCH PROGRAM

HNEI funded its first research projects in FY 1975-76 by supporting ongoing projects and providing "seed" funds, that is, initial low-level support for a preliminary study of a new idea or application. Many of these seed projects have led to more extensive programs, attracting significant funding from government and private sector sources. In the first two years HNEI awarded 32 grants for research in geothermal energy, bioconversion and solid waste, ocean thermal energy conversion, solar radiation, wind energy, and energy conservation, thus initiating a well-balanced program to investigate Hawaii's natural energy resources. By simultaneously proceeding with all resources that demonstrate promise, appropriate energy sources are sought for a variety of end uses.

A breakdown of the ten-year dispensation of projects funds, totalling \$8,616,490, is shown by technological categories in Table 2.

Table 2
HNEI PROJECTS BY TECHNOLOGY
1975-1984

BIOMASS ENERGY PROJECTS

Antal, Michael/ME-HNEI	Flash Pyrolysis Studies of Bio. Mat. Dissolved Supercritical Solvent	151,772
Antal, Michael/ME-HNEI	Continuous Radiant Decomposition Studies	65,000
Antal, Michael/ME-HNEI	Reactor/Recover Dev. for the Pyroly. of Biomass Using Solar Radiation	60,808
Antal, Michael/ME-HNEI	Mechanistic & Kinetic Studies of Gas Phase Pyrolysis Chemistry	25,390
Antal, Michael/ME-HNEI	Assess the State of Hawaii's Forest Potential as Source of Fuels	2,519
Antal, Michael/ME-HNEI	Initiate Research on Biomass Pyrolysis in Supercritical Fluids	26,865
Antal, Michael/ME-HNEI	Mathematical Modeling of Biomass Pyrolysis Phenomena	3,400
Brewbaker, James/Horticulture	Statewide Energy Tree Farm R&D	62,854
Chen, Charles/CER	Hawaii Ethanol from Molasses Project	71,555
Dugan, G./Takahashi P./CE	Research in Feasibility of Developing Bioconversion Systems	69,888
Dugan, G./Young, R./CE	Methane Generation from Solid Waste	13,909
Dugan, Gordon/CE	Design, Fabrication, and Operation of Innovative Microalgae Culture	4,500
Fox, Joel/ME	Combustion Properties of Biomass Pyrolysis Products	19,613
Fox, Joel/ME	Computer Simulation of Purox Pyrolyzer	13,138
Friend, D./Yamamoto, H./Botany	Biomass Productivity in Fast-Growing N-fixing Trees	14,000
Kihara, Deane/ME	Alcohol-Water Mixtures as Fuels	6,965
Laws, Edward/Oceanography	RD&D of Algal Production Raceway Systems	1,185,448
Miyashiro, Richard/MCC	100% Ethanol Vehicle Demonstration Project	7,572
Raymond, Larry/HNEI	High Efficiency Solar Energy from Algae	30,725
Takahashi, Patrick/CE	Biomass Integrated Waste Energy Production	11,100
Takahashi, Patrick/HNEI	Renewable Energy From Biomass	20,000
Yang, Ping-Yi/Agr. Eng.	Design Parameters for Anaerobic Conversion of Organic Wastes	11,475
Yang, Ping-Yi/Ag. Eng.	On-Farm Methane Generation with Sludge Recycling	21,918
Yuen, Paul/HNEI	Feasibility Study of Alternate Fuel Products	62,901
Yuen, Paul/HNEI	Application of Solar Generated Heat for Sugar Cane Processing	2,741
Yuen, Paul/HNEI	Selection of Efficient Yeast Strains	19,845
Yuen, Paul/HNEI	Alcohol Production from Molasses	11,235
Yuen, Paul/HNEI	Biomass Energy Options for Hawaii	36,246
TOTAL	28 Projects	\$2,033,382

GEOTHERMAL ENERGY PROJECTS

Chen, Bill/Hilo College	Scaling & Corrosion Experiments of Heat Exchangers w/ Geothermal Water	11,330
Chen, Bill/Hilo College	Interference Test & Reservoir Analysis of Kapoho Geothermal Reservoir	57,079
Cheng, Ping/ME	Boiling Heat Transfer in Geothermal Systems	30,627
Epp, David/HIG	Hydrology, Temperature & Chemistry of Water in the East Rift Zone	56,074
Helsley, C./Thomas, D./HIG	Geothermal Assessment	150,000
Htun, Ko Moe/ME	Corrosion of High-Temperature Materials in Volcanic Environment	10,065
Karl, David/Oceanography	Biological Sulfide Abatement	19,500
Kihara, D./Chai, H./ME	Heat Exchanger Design	11,792
Lopez, Louis/HGP-A	Geothermal Wellhead Generator	48,000
Manghnani, Murli/HIG	Seismic and Thermal Properties of Hawaiian Basalts	43,400
McMurtry, Gary/HIG	Geothermal Systems on the Submarine Rift Zones	12,000
Muenow, David/Chemistry	Mass-Spectrometric Studies of Metal-Magma Reactivity	14,265
Naughton, John/Chemistry	Helium Content of Volcanic Gases as Predictor of Geo. Potential	8,590
Peterson F./N.El-Ramley/HIG/DS	Non-Electrical Uses of Geothermal Energy: A Survey	4,724
Roelofs, Thomas/EE	Electromagnetic Exploration for Deep Geothermal Resources	5,293
Shupe, J./Thomas, D./HNEI/HIG	Geothermal Assessment Program	84,000
Siegel, S. & B. Botany/PBRC	Environmental Quality Studies	48,300
Siegel, Sanford/Botany	Phytotoxicity of Geothermal Fluids	13,765
Sinton, John/HIG	Shallow Magma Chambers & Geothermal Potential of the SW Rift Zone	10,214
Takahashi, Patrick/HNEI	Puna Geothermal Research Facility	325,000
Thomas, D./Naughton, J./HIG	An Evaluation of Inert Gas Abundance Patterns as Geothermal Tracers	14,053
Thomas, D./DeCarlo, E./HIG	Investigation of the Na/Li Geothermometer For HI Geothermal Systems	9,500
Thomas, Donald/HIG	Dike Water Relationships to Potential Geothermal Resource in Maui	7,500
Thomas, Donald/HIG	Geochemical Monitoring of HGP-A Geothermal Fluids	12,589
Yeh, Hsueh-Wen/HIG	Isotope Compositions as Clues to Circulation of Geothermal Fluids	15,418
Yuen, Paul/HNEI	Kapoho Geothermal Reservoir Synthesis	30,421
Yuen, Paul/HNEI	Reservoir Assessment for HGP-A Wellhead	193,112
Yuen, Paul/HNEI	HGP-A Wellhead Generator Facilities (TRW)	38,500
TOTAL	28 Projects	\$1,285,111

OCEAN ENERGY PROJECTS

Bathen, Karl/OE	Deep Moored Platform - Keahole Point	12,190
Bathen, Karl/OE	Environmental Baseline Studies at Keahole Point	22,094
Caperon, John/Look Lab	Ocean Energy Offshore Pipes/Barges	15,000
Caperon, John/Oceanography	Environmental Impact of Mini-OTEC Operation	51,754
Craven, John/OE	Dynamic Positioning for a Floating OTEC Plant	9,000
Fast, Arlo/HIMB	OTEC-Aquaculture Experiments at NELH	3,480
Grace, Robert/CE	Breaking Wave Forces on OTEC Pipes	59,121
Kroopnick, Peter/Oceanography	Environmental Effects of OTEC Chlorination	15,005
Larsen-Basse, Jorn/ME	Open-Cycle Evaporator Experiment with Seawater	16,700
Larsen-Basse, Jorn/ME	OTEC Test Facility Ke-Ahole Point	58,000
Larsen-Basse, Jorn/ME	Open-Cycle OTEC Experiments with Seawater	258,541
Lee, Theodore/OE	Dynamic & Hydronamic Responses to Waves & Currents	7,221
Lee, Theodore/OE	Hydrodynamic Loading on Shelf-Mounted OTEC Plant Structures	14,500
Lee, Theodore/OE	Laboratory Investigation of OTEC Impact on Environment	2,449
Lee, Theodore/OE	Engineering Development of a Directional Wave Spectrum	26,855
Liebert, Bruce/ME	Corrosion & Biofouling of Simulated OTEC Heat Exchangers	8,500
Marsh, James/BEC & QM	Economic Viability of OTEC	6,374
Munchmeyer, Fred/ME	Fouling & Corrosion in OTEC Heat Exchangers	13,242
Noda, Ed/Look Lab	OTEC Environmental Benchmark Survey	87,420
Noda, Ed/Look Lab	Bottom Current Survey Services	31,733
Noda, Ed/Look Lab	Preliminary Design Work of OTEC Conversion Pipeline Systems	24,928
Sansone, Francis/HIG/Ocean.	Nitrogenous Products of OTEC Chlorination and Effect on Aquaculture	12,000
Sansone, Francis/HIG/Ocean.	Environmental Effects of OTEC Chlorination	37,820
Taguchi, Satoru/HIMB/Ocean.	Effect of OTEC Waste Water on Natural Phytoplankton Assemblages	12,659
Takahashi, Patrick/HNEI	Non-Chemical Methods of Biofouling Control in OTEC Heat Exchangers	160,000
Yuen, Paul/HNEI	OTEC Assessment Project (Matching funds)	32,712
Yuen, Paul/HNEI	Ocean Energy	27,000
Yuen, Paul/HNEI	Hawaii OTEC Program	11,865
Yuen, Paul/Jones, Lloyd/HNEI	OTEC Heat Exchanger Biofouling Experiment	88,657
TOTAL	29 Projects	\$1,126,820

SOLAR ENERGY PROJECTS

Bathen, Karl/OE	Solar Pond Applications in Hawaii	37,465
Cheng, P./Larsen-Basse, J./ME	Reliability & Materials Performance of Solar Heating & Cooling Systems	7,905
Chou, James/ME	Optimization of a Solar Water Heating System	22,053
Curtis, George/HNEI	Direct Insolation Analysis and Site Evaluation, Isle of Molokai	28,951
Ekern, Paul/WRRC	Solar Resource Assessment	21,000
Holm-Kennedy, James/EE	High Temperature Solar Centrator Absorber H ₂ and H ₂ O	8,909
Holm-Kennedy, James/EE	Fabrication & Analysis of a Novel Concentrator PV Cell	46,706
Moy, James/Food Science	Solar Crop Drying	5,276
Neill, D. Richard/HNEI	Pacific Island Solar Radiation Assessment	12,370
Ramage, Colin/Meteorology	Solar Energy Meteorological Research (ERDA/DOE)	780,009
Shupe, J./Antal, M./HNEI	R ³ Lab	100,935
Shupe, John/HNEI	Operation of Wilcox Hospital Solar System, Year 2	466,757
Siegel, S./Speitel, T./Botany	Solar Still Greenhouse for Agriculture w/o Fresh Water	12,918
Takahashi, Patrick/HNEI	Residential Rooftop Photovoltaic Systems	429,443
Tseng, Cheng Chung/EE	A New Design for Photovoltaic Cells	8,544
Yoshihara, Takeshi/CE	Measurement of Solar Radiation	63,711
Yuen, Paul/HNEI	Solar Workshop	1,864
Antal, Michael/ME-HNEI	Solar Energy Laboratory on Roof of Holmes Hall	57,000
TOTAL	18 Projects	\$2,111,816

HYDROGEN ENERGY PROJECTS

Antal, Michael/ME-HNEI	Mechanism of Thermal Decomposition Sulfate Related with Hydrogen	4,254
Liebert, Bruce/ME	Electrochemical Evaluation of Hydrogen Systems Storage	45,180
Ming, Li Chung/HIG	Characterization of Metal Hydrides at High Pressures & High Temp.	3,850
Payne, Phillip/Chemistry	Characterization of Metal Hydrides Suitable for Hydrogen Storage	9,900
Pong, William/Chemistry	Study of Electrode/Electrolyte Interfaces for Meth. or Hydrogen Prod.	7,349
Sharma, Shiv/HIG	Interaction of Hydrogen & Deuterium with Transition Metals & Alloys	23,266
Sharma, Shiv/HIG	Mossbauer Spectroscopy for Metal Hydride Research	8,117
Siegel, Sanford/Botany	Hydrogen Sulfide Emissions and Health in Rotorua	12,000
Takahashi, Patrick/HNEI	Program Coordination and Administration	11,140
TOTAL	9 Projects	\$125,056

WIND ENERGY PROJECTS

Avery, Don/ME	Improved Wind Powered Water Pumping System	1,000
Cheng, Edmond/CE	Relating to Wind Energy Conversion	4,024
Cheng, Edmond/CE	Evaluation Technique for Wind Energy Application	11,866
Daniels, Anders/Meteorology	A Vertical Corrosion Profile Study in Kahuku, Oahu	4,404
Gopalakrishnan, Kakkala/HCC	Use of Alter. Energy for Supporting Intensive Aquaculture Operations	13,026
Hwang, Hu Hsien/EE	Hawaii Interisland Energy System Study	3,619
Hwang, Hu Hsien/EE	Wind Turbine Power Synchronization	4,077
Lee, Theodore/OE	Sail-Assisted Technology for Pacific Marine Transportation	22,746
Liang, Tung/Agr. Eng.	Wind Powered Irrigation Pumping for Land Reclamation	5,868
Ramage, Colin/Meteorology	Molokai Wind Survey	9,970
Ramage, Colin/Meteorology	Wind & Solar Measurement for Kauai	10,000
Ramage, Colin/Meteorology	Wind Power Survey on the Big Island	5,287
Schroeder, Thomas/Meteorology	Development of Wind Forecasting Program for Wind Farm Applications	4,900
Shupe, John/HNEI	Wind Energy Research Assessment and Applications	348,118
Shupe, John/HNEI	Wind Characteristics Program for Wind Resource Validation	8,000
Takahashi, Patrick/HNEI	Agreement for Battery Storage System	321,880
Ramage, Colin/Meteorology	Wind and Solar Measurements	119,812
Shupe, John/HNEI	Wind and Solar Application	19,109
TOTAL	18 Projects	\$917,706

OTHER ENERGY PROJECTS

Canan, Penelope/Women Studies	Baseline Socio-Economic Data Collection for Molokai ESS	5,330
Chai, Hi Chang/ME	Freon Boiler for Alternate Energy Power Cycles	23,995
Chou, James/ME	Building Energy Conservation in Hawaii	14,000
Hahn, Youngki/Hilo College	Economic and Social Impact of Renewable Energy Resource Development	8,088
Hwang, Mu Hsien/EE	Feasibility of Linking the Islands w/ Submarine Electrical Cables	5,565
Kamins, Robert/Economics	Pricing Natural Energy in Hawaii	14,048
Larsen-Basse, Jorn/ME	Corrosion Protection for Alternate Energy Systems of Interest to HI	103,718
Larsen-Basse, Jorn/ME	Definition of Test Program for Interisland Submarine Power Cable	75,097
Larsen-Basse, Jorn/ME	Corrosion & Fouling Removal	7,989
Leung, PingSun/Ag. Ec.	Demand Analysis of Ground Transportation Fuels in Hawaii	10,342
Pearson/	Conservation Brochure	13,585
Shupe, John/HNEI	Promotion of Solar Energy Research Institute	16,408
Takahashi, P./Masuda, R./CE	Energy Self-Sufficiency for Maui	32,366
Takahashi, Patrick/HNEI	UHM/HNEI Electrical Vehicle Program	442,962
Thompson, /Pearson	Instrumentation of the Hawaiian Energy House	6,431
Yuen, Paul/HNEI	Legislative R&D Workshop (MITRE Corp.)	38,887
Yuen, Paul/HNEI	Energy RD&D Project Support	54,604
Yuen, Paul/HNEI	Social, Environmental, Legal, & Economic Aspects of ESS	1,569
Yuen, Paul/HNEI	Molokai Community Energy Management Plan	6,285
Yuen, Paul/HNEI	For Research and Developing Energy Self-Sufficiency for Kauai	19,902
Yuen, Paul/HNEI	National Conference on Renewable Energy Technologies	79,564
Siegel, Sanford/Botany	Environmental Overview Program for Alternate Energy Development	35,864
TOTAL	22 Projects	\$1,016,599

The following sections of this report will review the history of renewable energy research in Hawaii—in biomass, geothermal, direct solar, OTEC, wind, and other technologies—with highlights of HNEI's role and contributions.

COOPERATION IS KEY TO ENERGY SELF-SUFFICIENCY

Hawaii has played a "pathfinder" role in the transition to renewable energy resources and in seeking greater energy self-sufficiency. The wide scope of alternative energy programs is characterized by close cooperation among the participants: the counties, private industry, the federal government, the University of Hawaii, led by HNEI, and other state agencies, particularly DPED.

Beginning in 1976 HNEI became involved in helping the counties to develop their own resource plans. The energy use pattern for each county was studied, followed by projections of renewable energy supplies. The purpose of these forecasts was to obtain energy balance sheets that would help to plan energy self-sufficiency scenarios. The 1976 Hawaii County plan and a two-day symposium on the subject spotlighted national attention on the concept. A follow-up study of Hawaii County was funded by USDOE in 1978, and a report was prepared by the Stanford Research Institute. The report proposed five scenarios for future energy demand ranging from business-as-usual to strong emphasis on new industries, with various supply futures proposed for each scenario. Public meetings were held to review the social and environmental impacts of the scenarios and to obtain citizen input. Today the Big Island is able to supply more than 40 percent of the energy needed for electrical generation from local sources of biomass, geothermal energy, and wind energy.

Self-sufficiency studies were conducted by Maui and Kauai Counties with the assistance of HNEI. A 1979 Kauai study showed that the county was already more than 50 percent self-sufficient for its total electrical energy requirements. Sugar mill bagasse provides for its own process steam requirements plus 33 percent of the public utility's electricity demand. Aviation fuel is not a major component of Kauai's energy demand since few interisland flights refuel there.

The City and County of Honolulu adopted an energy policy statement as a component of its general plan and departmental staff were involved in planning for both conservation and alternative energy development. Honolulu faces the greatest difficulties in attaining energy self-sufficiency because of its large population concentration—more than 80 percent of the state's population resides



In August 1980, Dean Paul Yuen, Governor George Ariyoshi, and U.S. Senator Spark Matsunaga presented a proposal for Hawaii energy self-sufficiency to John Sawhill, who was then Deputy Secretary of the U.S. Department of Energy.

on Oahu, consuming 90 percent of the state's total petroleum imports. Sugar mills use bagasse-generated electricity for irrigation pumping and have little excess to sell to the utility. For state-wide energy self-sufficiency, Honolulu would need to import power and fuels from the other counties.

Realizing the ambitious goal of total or even partial energy self-sufficiency would benefit Hawaii in many ways: the establishment of a secure, reliable source of energy free from strikes and embargoes or other foreign actions; the creation of new, long-term jobs; the encouragement of economic development; and the savings of dollars currently used to pay for imported petroleum. Hawaii's progressive and aggressive pursuit of energy self-sufficiency has attracted national interest and cooperation. USDOE chose Hawaii in 1980 as the site of its first National Conference on Renewable Energy Technologies, which had as its theme, "Island Self-Sufficiency as a Model for National Energy Development." The conference drew 1,000 participants and had 250 invited speakers. The conference solidified HNEI's role in the national renewable energy research program and identified Hawaii's energy situation as a microcosm of more global issues. Federal support of renewable energy programs has fluctuated; however, even with sharp cutbacks under the Reagan administration, HNEI was successful in obtaining a three-year, \$500,000 institutional grant from USDOE for research on energy alternatives in 1980. This was the agency's eighth and final award to outstanding energy research universities, and the only one for renewable energy.

Many of Hawaii's alternative energy programs have become showcases of achievement using these indigenous resources. The experience gained may have direct spinoffs to other areas or offer insights to regions with the potential to undertake similar projects, especially other island communities. This past year, HNEI's cooperative efforts have broadened to the international level with participation in the energy component of the Pacific International Center for High Technology Research (PICHTR). International attention was also focused on the Hawaii Hydrogen Program as a result of the first Hawaii International Symposium on Hydrogen Produced from Renewable Energy held in May 1984.



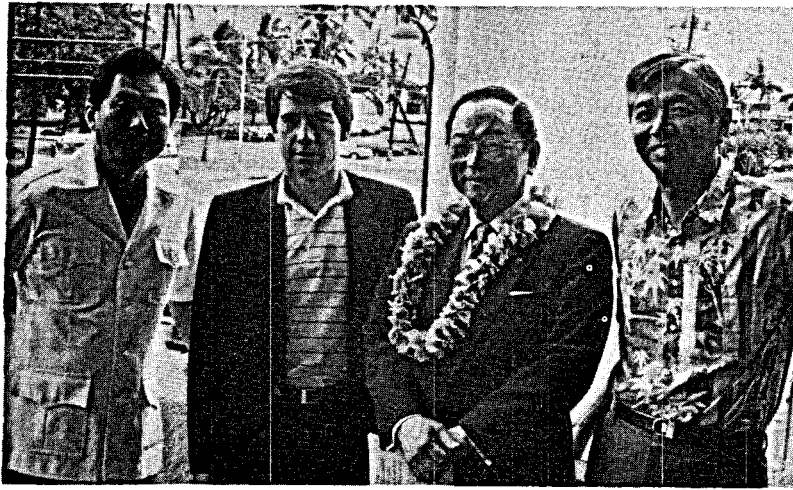
The three directors of the Tri-State Consortium—from left, Patrick Takahashi, Hawaii Natural Energy Institute; Harry Zwibel, New Mexico Solar Energy Institute; and David Block, Florida Solar Energy Center.

At the national level, a cooperative agreement has been signed with the Florida Solar Energy Center and the New Mexico Solar Energy Institute. In addition, joint programs are in progress with the Solar Energy Research Institute, the Applied Physics Laboratory of the Johns Hopkins University, and various national laboratories.

At the state level, HNEI has cooperated with the private, public, and academic communities. HNEI coordinates the University of Hawaii's energy research efforts, and public utilities and private companies have close working relationships with both HNEI and the university. In 1982 Coral Industries Inc. endowed the first university chair in renewable energy resources in the nation, with Michael Antal, Jr. appointed as the first chairholder. Hawaiian Electric Industries in 1983 joined the Atlantic Richfield Foundation, General Electric Foundation, Chevron U.S.A. Inc., Advanco Corporation, and Basix Corporation in providing funds for the Spark M. Matsunaga Fellows in Renewable Energy Engineering (FREE) program, for which candidates are currently being sought. Pacific Resources Inc. (PRI), Hawaiian Electric Industries, the Hawaiian Sugar Planters' Association, and numerous manufacturing, engineering, and consulting firms have also cooperated on research and other projects with HNEI.



Michael Antal, Coral Industries Professor of Renewable Energy Resources, is welcomed by then UHM Energy Research Coordinator John Shupe (center) and then UH President Fujio Matsuda (right).



The FREE Program is a partnership of the Hawaii Natural Energy Institute (Patrick Takahashi); Renewable Energy Institute of Washington, D.C. (Robert Hayden); U.S. Senator Spark Matsunaga; and the UHM College of Engineering and Pacific International Center for High Technology Research (Paul Yuen).



The first fully-funded FREE fellowship award from Hawaiian Electric Industries is signed by (left to right) HEI President Dudley Pratt, former UH President Fujio Matsuda, and past UH Foundation President John "Doc" Buyers, while U.S. Senator Spark Matsunaga looks on.

HNEI's most important partnership has been with the State Department of Planning and Economic Development. HNEI and DPED, often in conjunction with other governmental and private organizations, have been responsible for most of the renewable energy developments in the state. HNEI usually assumes the research and development role, while DPED handles responsibilities related to commercialization and energy conservation. From the participation of international authorities at an HNEI-sponsored workshop to an elementary school show-and-tell on electric vehicles, HNEI assists and supplements an active program of basic research, technology transfer and education.

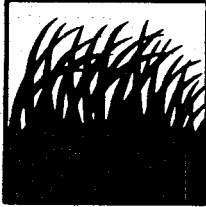


The first national conference sponsored by the Energy Division of the American Society of Civil Engineers provided a broad forum for discussion of energy issues. Participating in Energy '84 were (left to right) DPED Energy Program Administrator Takeshi Yoshihara, U.S. Representative Daniel Akaka, and HNEI Director Patrick Takahashi, who served as Conference Chairman.

Thus, the history of the Hawaii Natural Energy Institute is an integral part of the story of renewable energy development in Hawaii. The obstacles to ultimately achieving energy self-sufficiency are formidable, but the benefits are worth that effort—the future vitality of Hawaii is being nurtured in the activities of HNEI today.



Acting UHM Chancellor Richard Kosaki (left) with Representative Tom Okamura conferring during a recent HNEI briefing for legislators.



BIOMASS ENERGY RESEARCH

TEN-YEAR HISTORY

INTRODUCTION

Biomass is Hawaii's most versatile renewable energy resource. In addition to being a primary feedstock for steam and power generation, this resource can be converted to various fuels: alcohols, synthesis gases, and even long-chained hydrocarbon fuels equivalent to petroleum-derived fossil fuel. Steam and power generation from biomass have been used commercially for many years. However, while the conversion processes to liquid fuels are technically feasible to varying degrees, they are not yet economically attractive.

The Hawaii sugar industry provides about 8.6 percent of the state's electricity generated by burning bagasse, a sugar cane processing residue, as boiler fuel. Of the state's twelve sugar companies, Kauai's plantations have provided the largest share of bagasse energy, almost 62 percent of the gross electricity generated on that island. This is followed by Hawaii, Maui, and Oahu, with 42 percent, 27 percent, and 2 percent, respectively.

The early projections of the State Advisory Task Force on Energy Policy in 1975 stated that with an intensive effort, the amount of biomass-based electricity could be doubled with the use of forest wood, pineapple trash, and sugar cane trash. During the subsequent ten-year period a number of events have occurred, setting a foundation for eventual larger scale utilization of biomass.



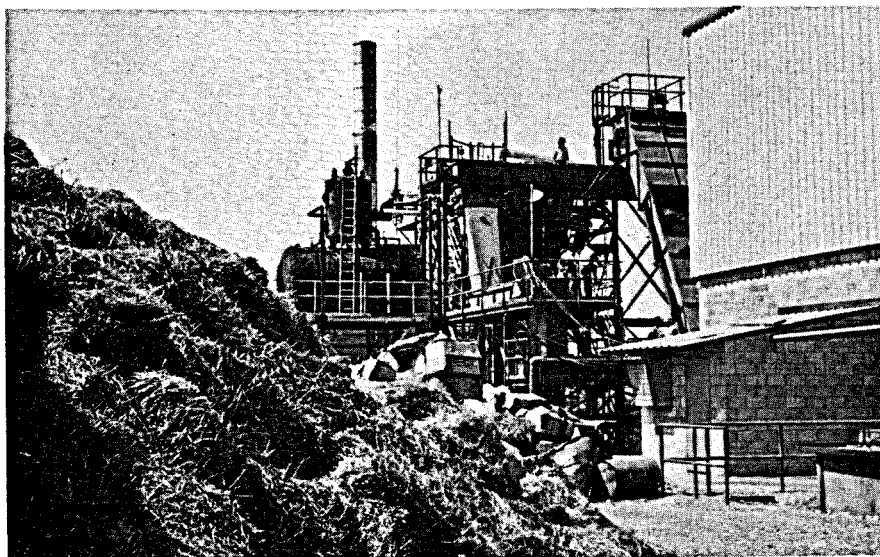
Sugar cane and the Hamakua Sugar Mill on the Big Island: The Energy Cane Alternative?

In 1977 the Hawaii State Legislature enacted Act 102 (Sec. 269-1, 269-27.2 H.R.S., as amended) to encourage greater development of biomass produced electricity by exempting the sugar companies from the control of the Public Utilities Commission and to enable the companies to receive a fair price for their power. The Hawaii legislation predated the federal Public Utilities Regulatory Policy Act (PURPA), passed in 1978 to encourage the generation of electricity from non-fossil fuel resources. PURPA requires utilities to buy excess power from any small electrical generator (less than 80 megawatts in size) at the utilities' avoided cost. The State Public Utilities Commission has based their interpretations on the federal regulation. State law provides that if the two parties cannot agree upon a set price for the power, then the PUC will intervene to make a determination.

HAWAII BIOMASS USE

The state and federal laws thus provide incentives for the sugar companies to sell their excess electricity and to expand their power plant facilities. Lihue Plantation Company on Kauai has installed a boiler capable of burning bagasse, sugar cane trash, wood chips, municipal refuse, and fuel oil. The Hawaiian Commercial and Sugar Company on Maui recently added a new turbo-generator to increase its generating capacity. The processing facility at Davies-Hamakua Sugar Company on the Big Island incorporates a pelletizer, which converts bagasse into energy pellets, to increase output capacity and to provide storage capabilities that will make firm power available for twelve months of the year.

Molokai Electric Company's biomass generating facility began operation in May 1982. This biomass boiler, capable of burning a variety of biomass fuels—including hay, wood chips, pineapple chop, and waste paper—and with the addition of a gas turbine and waste heat boiler would be able to provide 60 to 70 percent of the island's electrical energy. Unfortunately, a mechanical breakdown of the generator caused a temporary shutdown of the system.



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

Besides bagasse-burning, wood chips from trees can also be used as a replacement for fuel oil. The State Division of Forestry (SDF), which has been conducting a tree planting program for many years, recently increased the propagation of seedlings at the Waimea State Nursery on the Big Island and is expanding the planting of eucalyptus trees throughout the state. SDF has calculated that the potential demand for eucalyptus as a wood fuel would necessitate 20,000 productive acres. Over 100,000 acres of state forest land have been identified as potential sites for energy tree farms.

BioEnergy Development Corporation, a subsidiary of C. Brewer & Co., has just completed its marginal sugar cane land. Approximately 620 acres of trees have been planted to date in order to conduct various experiments on fertilization, spacing, appropriate species and intercropping patterns, genetic improvement, weed control, and nursery practices.

Mauna Loa Macadamia Nut Corporation utilizes the nut shells as a high-Btu source of fuel to produce steam and electrical energy for their processing plant. With the rapid expansion of macadamia nut orchards in the state, the further exploitation of this energy source should be considered.

In June 1980, the County of Maui examined the feasibility of recovering dried pineapple chop for use as a biomass fuel in electrical generation on the island of Molokai. The study concluded that it would be advantageous to recover the biomass as fuel and return the ash to the fields; however, Del Monte Corporation has since suspended its pineapple plantation operations on that island.

The production of ethanol from sugar cane molasses offers the best potential for the near-term development of a liquid fuel from an indigenous resource. Fermentation of carbohydrates to ethanol is a well-known process with numerous distilleries in operation in the U.S. and throughout the world, including a small rum plant on Maui that utilizes molasses as the feedstock.

Pacific Resources Inc. (PRI), in cooperation with Aloha Petroleum, began a marketing test in 1979 to determine the public's acceptance of gasohol produced from imported mainland ethanol. The fuel did not prove to be economically feasible due to the high ethanol cost and was discontinued in 1982. In 1981 PRI suspended plans to build an ethanol-from-molasses plant.

A comprehensive study funded by USDOE and conducted in 1981 by C. Brewer & Co. assessed the feasibility of an 11.4 million-gallons-per-year ethanol plant at their Hilo Coast Processing Company facility on the Island of Hawaii, which was found to be economically feasible with federal and state tax credits. The Governor's approval of House Bill No. 1262 authorized the issuance of \$10 million of special purpose revenue bonds for the construction of an ethanol plant. Subsequently, C. Brewer decided to utilize \$15 million of private financing instead of state money. Negotiations were progressing for long-term purchase commitments of the ethanol by the oil industry for blending with gasoline; however, after many months of discussion, the board of directors finally tabled plans for a 5-million-gallon ethanol plant because of failure to secure a satisfactory contract with an oil company and concern about the possible termination of the federal tax credit as of December 31, 1985.

Municipal solid waste (MSW) can be considered a biomass resource since its organic components are combustible in a resource recovery facility or can be converted to transportation fuel. Kauai, Hawaii, and Maui Counties are actively pursuing plans for possible utilization of MSW as an energy resource. The City and County of Honolulu's resource recovery project, called H-POWER when it was first proposed in 1978, has been delayed for a variety of reasons.

HNEI BIOMASS ENERGY RESEARCH PROJECTS

HNEI involvement in biomass research projects has been divided into three areas: solid, liquid, and gaseous fuels.

Solid Fuels

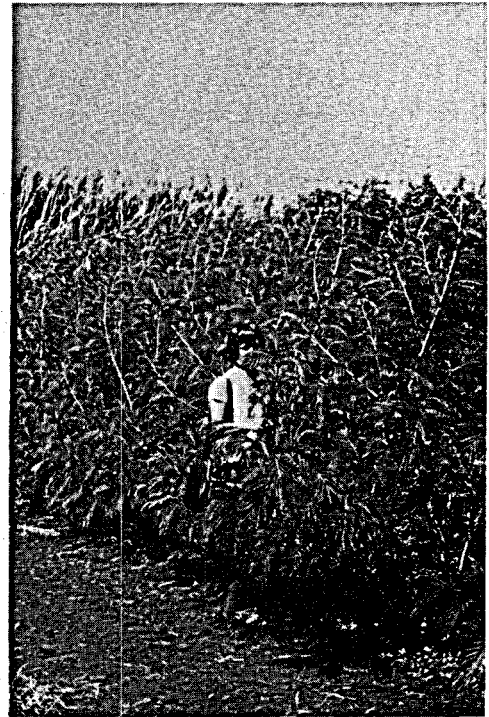
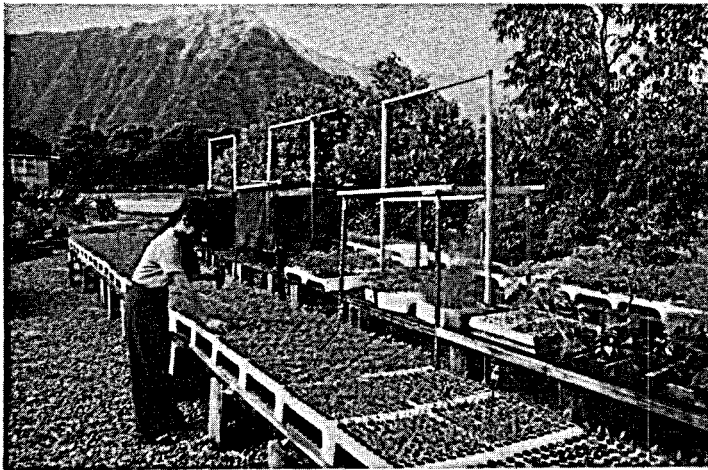
Hawaii's sugar plantation companies utilize bagasse for approximately 88 percent of their steam generation needs and generate about 10 percent of the total electrical energy produced in the state. Efforts are under way to utilize more cane trash (tops and leaves) and wood chips to increase boiler output, to reduce factory energy losses, and to utilize waste heat to reduce bagasse moisture, thereby increasing the energy value. A company is presently pelletizing bagasse for storage of this fuel, and another has initiated a gasification program.

An energy tree farm study on the giant leucaena, commonly known as the giant koa haole, was conducted for the Island of Molokai in 1980 by James Brewbaker. The objectives were to determine the economic feasibility of this species for the production of wood chip fuel, primarily for electrical generation, and to evaluate the concept of energy tree farms in general for Hawaii. The final report suggested that this type of tree farm could be a profitable enterprise on Molokai and could provide an economical source of biomass on marginal lands throughout the state. Brewbaker's current work is progressing toward the establishment of pilot-scale giant leucaena farms of two to ten acres on the major Hawaiian islands. A project conducted by Douglas Friend and Harry Yamamoto in 1983-84 investigated the factors associated with high yield in giant leucaena as compared with the common variety (wild leucaena). This research also is continuing through 1984-85.

The Big Island was selected for two different tree farm feasibility workshops, one considering the abandoned Puna sugar cane lands for tree farms, and the other evaluating the economic feasibility of eucalyptus tree farms for use in a synthetic fuels plant. The results were similar: the economics were marginal at best. Another study funded by the State in 1983-84 under Michael Antal assessed the potential of Hawaii's existing forests to serve as a renewable source of fuels and recommended composite mapping using new computer techniques, identification of areas where thinning



James Brewbaker inspecting leucaena growth as part of the State-wide Energy Tree (SET) trials on the major islands.



*Clockwise from top left:
leucaena as seedlings; six-month-
old plantings; harvesting of four-
year-old leucaena (Waimanalo
Experiment Station, UH College
of Tropical Agriculture and
Human Resources).*

practices might be used, and gathering of growth information for species represented. At the same time, caution was advised against excessive logging practices that could disturb the forest ecology and destroy critical animal habitats.

In response to the energy problems of the Pacific Island nations, research was initiated in 1982 by the Saipan Research Panel, a group of 17 biomass experts funded by USDOE, to examine the biomass resource of the U.S. Pacific Trust Territories. The objectives were to collect data, review them in relation to solid, liquid, and gaseous biofuels options, and establish priorities based on the commercial feasibility of the options. The report, *Biomass Energy Options for the American Territories of the Pacific*, by James Brewbaker and Kenneth MacDicken, recommended site adaptation, demonstration projects on tree farms and biomass gasifiers, economic feasibility study of energy tree plantations, and complete soil and vegetation assessments.

Liquid Fuels

An HNEI study funded by USDOE was conducted in 1979-80 under Paul Yuen with support from the Hawaiian Sugar Planters' Association to determine the best available ethanol production processes. Through staff visits to various ethanol plants in the U.S. and abroad, six processes were determined to be best suited to conditions in Hawaii. An evaluation was made of several environmentally acceptable alternatives for handling stillage, but a recommended follow-up study has not been pursued.

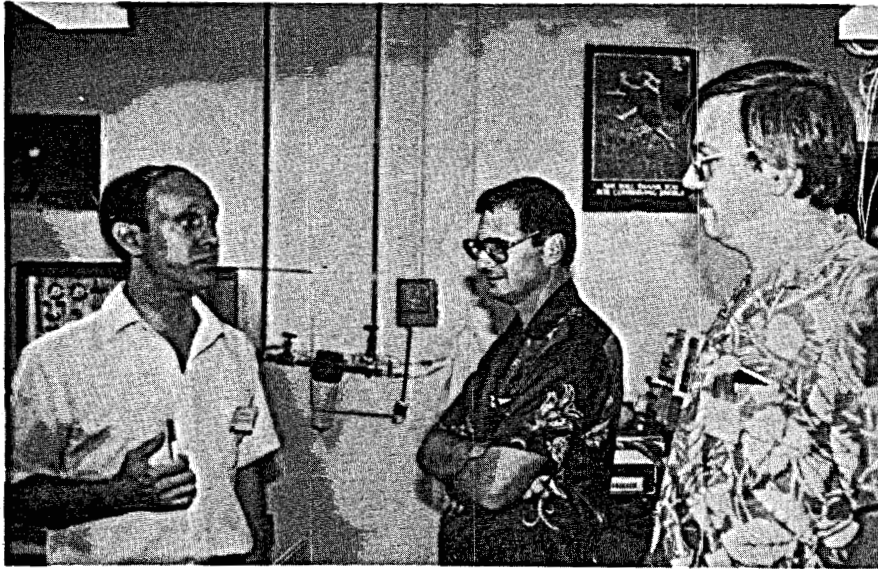
In preparation for the ethanol production study, another research project in 1978, also under Yuen, examined the characteristics of Hawaiian molasses and stillage. The objectives were to obtain and study data relating to the processing of molasses and stillage to determine the economic feasibility of producing fuel-grade ethanol in the Seagram rum plant at Puunene, Maui.

Concurrently with the stillage project, another research project was carried out to select and develop commercially available yeast cultures that would produce the highest possible yield of alcohol from sugar in Hawaiian molasses. This was accomplished by screening yeast strain samples obtained from suppliers and assessing the alcohol, acid, and sugar tolerances, as well as growth and yield constants of initial and selected yeast strains, and by determining the relationship between the heat treatment of molasses and yields of alcohol and yeast.

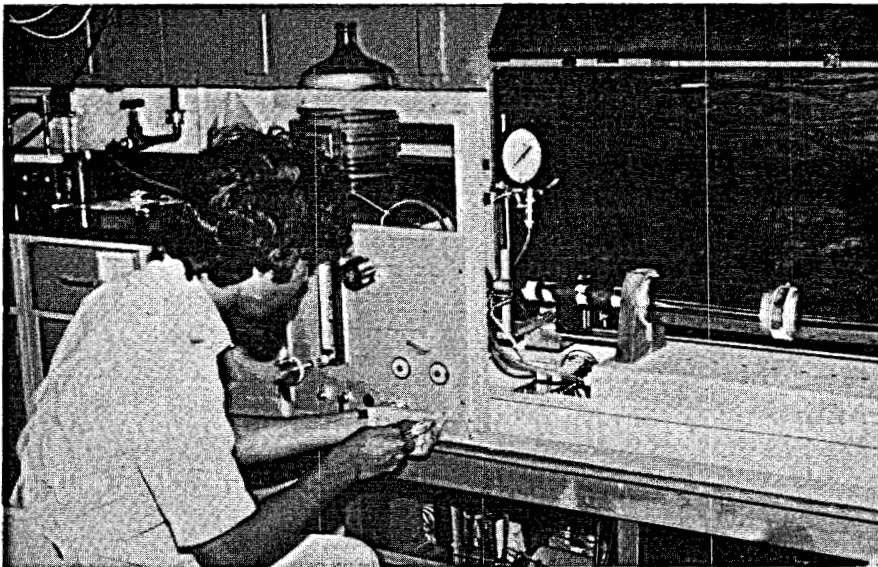
A 1982 biomass-to-liquid fuels study, sponsored by USDOE, allowed PRI, HNEI, and the Institute of Gas Technology to assess the economic feasibility of hydrolysis for the Hawaii energy market. Tree farms were considered for the biomass feedstock, and the final report concluded that, although hydrolysis is both scientifically and technically possible, it is not commercially feasible at this time due to the high cost of feedstock and the poor quality of the resultant fuel oil.

Stone and Webster Engineering Corporation of Boston, with the cooperation of HNEI, received two ethanol plant design awards from the Solar Energy Research Institute in 1983: one for acid hydrolysis and the other for enzymatic hydrolysis of lignocellulose. The site selected for these projects was the Island of Hawaii, with eucalyptus as the feedstock. Stone and Webster also received a third award to study a modular biomass-to-methanol plant. Methanol is considered a strong contender as an alternative fuel in Hawaii. Research in these projects is directed toward assessing the economic and technical feasibility of the technologies and determining areas for further R&D prior to commercialization by the private sector.

Michael J. Antal, Jr., the UHM/HNEI Coral Industries Professor of Renewable Energy Resources, has been conducting both basic and applied research in techniques for the conversion of biomass into liquid fuels since 1982 at the UHM Renewable Resources Research Laboratory. His research has included flash pyrolysis of biomass via a simulated solar concentrator, design and construction of a reactor for experimental pyrolysis of cellulose-related compounds, and pyrolysis in supercritical fluids. Among Antal's research results, he has discovered that all basic biomass components (cellulose, hemicellulose, and lignin), including the intermediates (anhydrocellulose and levoglucosan), degrade during their pyrolysis by similar competitive reactions, with the formation of char and tar competing for the solid feed and the formation of refractory tar and gases competing for a reactive volatile intermediate. This scheme of competitive reactions is identified as the "global" mechanism governing biomass pyrolysis. Antal's research is essential to the development of cost-effective processes for the eventual conversion of cellulosic types of biomass to liquid and gaseous fuels.



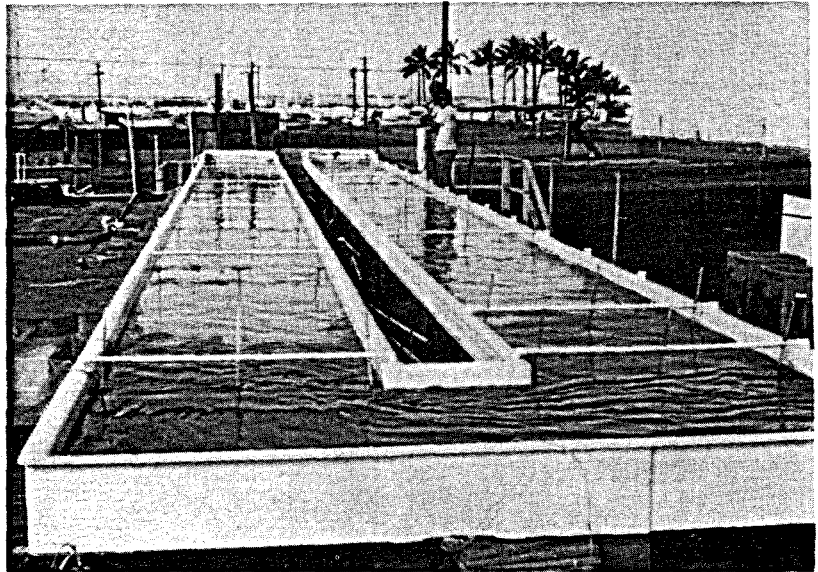
Coral Industries Professor Michael Antal, Acting President Albert Simone, and Acting Vice Chancellor for Research and Graduate Education David Morrison touring the Renewable Resources Research Laboratory in Holmes Hall.



Assistant researcher making adjustments to supercritical flow reactor which is used to convert molasses and sugars to chemicals.

Algae grown in coastal waters under Hawaii's abundant sunlight conditions offer potential as a future source of liquid fuels. Gordon Dugan and Patrick Takahashi made a thorough study of algal mass culture between 1975 and 1977, reviewing its history, biological characteristics, environmental impacts, product potential, and further research and development requirements. They also made an analysis of algae production using manure to supply nutrients. The project entailed engineering and economic analyses exploring the feasibility of establishing an integrated, self-sustaining bioconversion operation for the production of protein and energy. A third part of this research was to examine both freshwater and marine algae production with the purpose of determining the feasibility of culturing both types of alga species.

In 1976-77 Larry Raymond was funded by HNEI to study the feasibility of algae production and to build a small algal raceway. His favorable results initiated a proposal to USDOE, which was referred to the Solar Energy Research Institute (SERI). A SERI contract was awarded in 1979 with John Caperon as principal investigator, who was succeeded by Ed Laws in 1980. The objectives of this long-term project are to grow algae in a high-density mass culture system, harvest the cells, and determine their lipid content and characteristics and their potential as petroleum-fuel substitutes. This project has continued since 1979 with funding from SERI, HNEI, and DPED.



Edward Laws (left), principal investigator, and (right) algae, cultivated in this shallow outdoor raceway at Snug Harbor, will be tested for their energy content.

The Governor's Advisory Committee on Alternative Energy Development in November 1983 appointed a Transportation Fuels Task Force, headed by Michael Antal. The task force has as its members representatives from business, government, and the university, will make recommendations for broadening the fuel resource supply base for Hawaii by encouraging the development of methanol, ethanol, methane, and hydrogen fuels as alternatives to petroleum.

Gaseous Fuels

Methane gas produced from the anaerobic digestion of organic matter could serve in the future as an alternative to fossil fuels for mobile as well as stationary engine applications. A study was made in 1978-79 by Gordon Dugan and Patrick Takahashi to assess the overall potential of methane gas in Hawaii by identifying and evaluating sanitary landfill operations, animal wastes, and wastewater treatment plants as sources of biogas production.

Ping-Yi Yang in 1977 investigated the operational performance of an anaerobic digestion process of swine wastes for more efficient biogas production. The HNEI- and EPA-funded research was directed toward the development of an economical system for on-farm methane generation, sludge recycling, and pollution control. Later, Yang sought to demonstrate the management of methane production from swine wastes at the Happy Hula Hog Farm on Maui. He investigated direct combustion of biogas as an energy source for the various requirements of the farm. The objectives of this project were twofold: to establish design and operational criteria of anaerobic bioconversion of swine wastes and to determine the feasibility and design criteria for a partially aerobic treatment process with and without pretreatment of the swine wastes.

Using the research results of the previous study, an efficient anaerobic digestion system was designed for the Nakamoto Poultry Farm in Kona. Four vinyl bladder-type anaerobic digesters were installed for conversion of chicken wastes to biogas which is being used to dry macadamia nuts. The remaining sludge is sold as fertilizer.

Besides animal manure, Yang has conducted research on biogasification through the anaerobic digestion process of tropical biomass and organic wastes, including guava and papaya processing wastes and seaweed. An evaluation of technical, economic, and environmental factors relating to biogasification resulted from in this study. Following the results of Gordon Dugan's research on an integrated bioconversion system, Yang and S. Y. Nagano in 1983 concluded that algae cultivation in organic wastes for anaerobic digestion is technically feasible for pollution control and bioenergy production and utilization. HNEI has funded a pilot-plant operation to develop field designs and operating criteria for anaerobic digester and algal biomass raceway processes.

Pyrolysis of biomass (subjecting organic matter to very high temperature) is another technique for obtaining gas which has many positive characteristics as a fuel source, including the fact that it burns cleanly and is easily transported. Unfortunately, the variability of the gas composition, along with a relatively low energy value, serves to limit its acceptability as a fuel source. Thus there is a need for information on the fundamental combustion characteristics of a wide range of possible pyrolysis gas compositions in order to provide combustion engineers with a greater degree of confidence in substituting pyrolysis gas for standard fuels. Since 1982, Joel Fox has been involved in a series of tests to determine these characteristics for the range of fuel gas compositions approximating the pyrolysis products likely to be produced from Hawaiian biomass.

Research on hydrogen as a fuel is quite recent in Hawaii. In 1981 a USDOE grant supported a basic research project conducted by Bruce Liebert to study the hydrogen storage characteristics of various materials. Then, in 1983, the Hawaii Hydrogen Program was initiated by Patrick Takahashi, spurred by an appropriation of \$50,000 by the Hawaii State Legislature for research and development of hydrogen as a fuel. This appropriation funded seven basic research projects in FY 1983-84.

THE FUTURE OF BIOMASS TECHNOLOGIES IN HAWAII

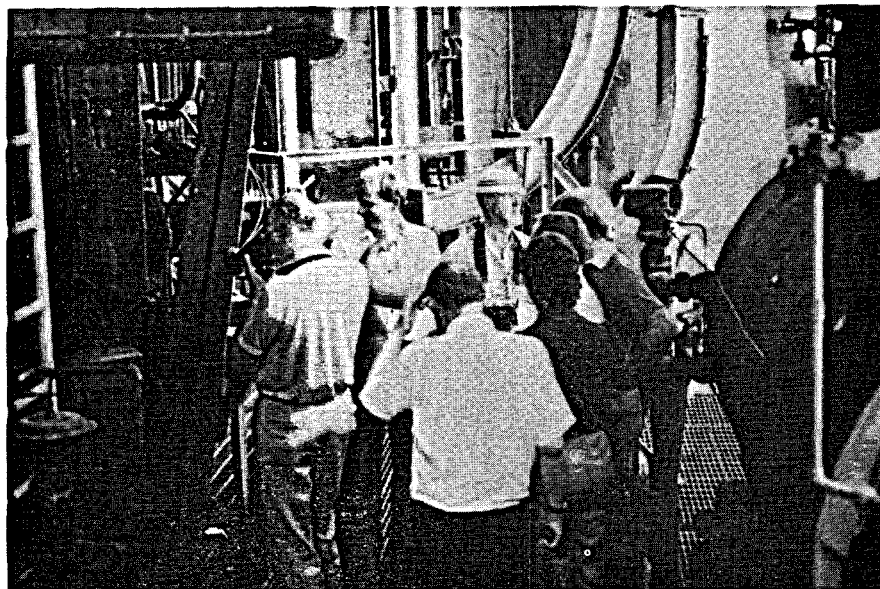
Once the dominant industry in the state, the sugar plantations have faced troubled times in recent years. Foreign competition and the instability of federal government support leave the future of the sugar industry in question. The recent closing of the Puna sugar plantation, with others possibly to follow, and the decline of productive sugar cane acreage threaten to handicap the state's economy and diminish its electric power production from a renewable energy source. The energy plantation—a major tree and herbaceous crop planting program that could target abandoned cane and pineapple fields—is a concept that is being examined as an economic substitute for the financially ailing sugar industry. The biomass grown would be burned for power generation or used as a feedstock for chemical or liquid fuel production.

It is evident that electricity from indigenous resources can be provided in a number of ways—geothermal steam, ocean thermal differentials, hydroelectric power, wind, solar energy, and, of course, biomass energy. The majority of the State's efforts toward energy self-sufficiency have been directed to electrical energy, which represents less than 30 percent of energy demand in Hawaii. As transportation fuels account for more than 50 percent, HNEI is beginning to look more closely at biofuels with an aim towards reprioritization.

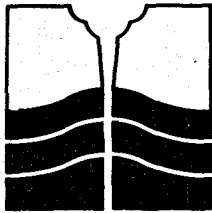
In response to a legislative request, DPED, HNEI and the State Department of Agriculture surveyed the state to determine how agri-crops could be made more cost effective. *Agri-Energy Research and Development in Hawaii*, published in November 1983, recommends ethanol production from molasses, corn, or other crops as the most feasible biomass-to-energy process for the near term. It also recommended continued state support for basic research in new technologies for the production of liquid and gaseous fuels from biomass, particularly algal growth and conversion, hydrogen fuel production, and pyrolysis processes.

Momentum has been gained in the search for alternative fuels for the state. HNEI has embarked on hydrogen research by supporting the efforts of researchers on campus and working cooperatively with the Florida Solar Energy Center toward development of this fuel. Coral Industries Professor Antal has been actively pursuing the field of liquid fuel production from biomass feedstocks. Basic research is needed to understand the process of converting organic matter to fuels and chemicals. At the same time, additional developmental research on equipment design and operation is required so that the desired end products and yields can be obtained.

A biofuels workshop was held in November 1984 to identify the various crops for which further research and development efforts are needed, to examine available and emerging conversion technologies, and to formulate a plan for implementing the recommendations. Researchers, scientists, and engineers from universities, government, and the private sector shared their views on these subjects, and preliminary plans for selecting suitable species and conversion processes for the state are being developed from the workshop information and reports. This coordinated state-wide effort will help Hawaii to converge on promising avenues of biomass energy research and development and to serve as the testing ground for the nation and the Pacific Basin.



Participants of the Pacific Basin Biofuels Workshop inspecting the biomass boiler on a tour of the Puna Sugar Mill.



GEOHERMAL ENERGY RESEARCH

TEN-YEAR HISTORY

INTRODUCTION

Each of the islands in the Hawaiian Archipelago is the top of a volcanic mountain rising from the ocean floor. This island chain was formed from the northwest to the southeast, following the movement of the earth's surface over a geological "hot spot" in the earth's mantle. The Big Island of Hawaii, the largest and youngest in the chain, continues to grow, fed by periodic eruptions of Mauna Loa and Kilauea Volcanoes. Yet another island is forming thousands of feet below sea level about 20 miles southeast of the Big Island.

The geothermal energy resource of the state comes from the heat of underground magma, which is transferred to water-saturated rock forming hydrothermal reservoirs. The hot fluid can be tapped by drilling wells from the surface, which releases steam and water for generating electricity and provides process heat for industry and agriculture.

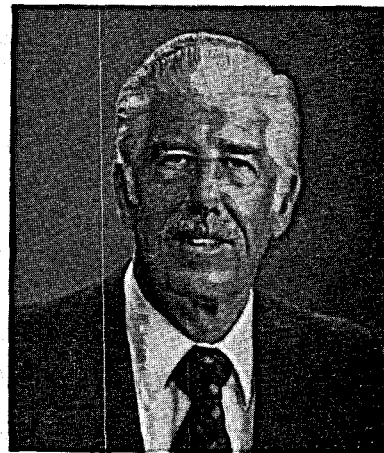
Geophysical and geochemical studies of HGP-A, the first energy-producing well, and the surrounding area have led to estimates that the Kilauea East Rift Zone has sufficient geothermal fluids to provide 50 to 3,000 megawatts of electricity for approximately a century. A resource assessment of the state has identified other sites with potential for productive geothermal wells.

THE HAWAII GEOHERMAL PROJECT

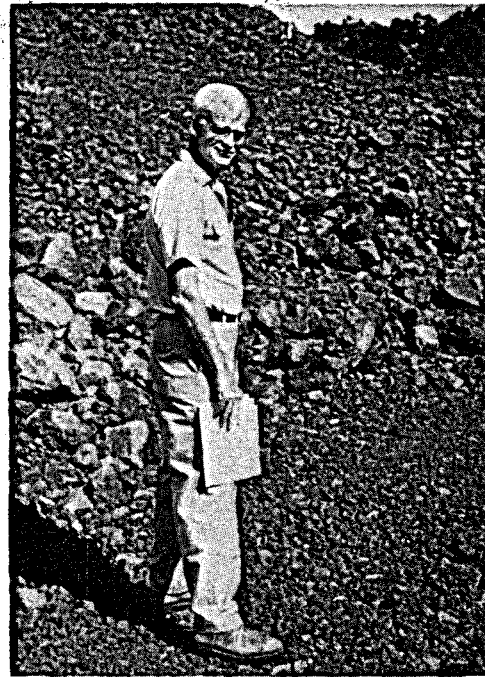
Hawaii's active involvement in geothermal energy began in 1972 when the State Legislature allocated \$200,000 to the Hawaii Geothermal Project to focus the research capability of the University of Hawaii on the identification and utilization of Hawaii's geothermal resources. John Shupe, dean of the College of Engineering, was the principal investigator for the project.

Research got under way in the summer of 1973, with separate programs established in three areas: geophysics, headed by Augustine Furumoto; engineering, Paul Yuen; and environment-socioeconomics, Robert Kamins. Several potential areas were identified and surveyed before the site selection committee, chaired by Agatin Abbott, selected a well site in the Puna District on the eastern rift of Kilauea Volcano.

The initial drilling through tough lava rock was difficult, and it took the drilling team, under Gordon Macdonald, five months to complete the well to a depth of 6,450 feet in April 1976. Other researchers who took an active role in the project were Bill Chen, Deane Kihara, Ping Cheng, and Patrick Takahashi. The well was dedicated as



John Shupe, principal investigator and project director of the successful Hawaii Geothermal Project.



Agatin Abbott (left) chairman of the site selection committee, and Gordon Macdonald who directed the drilling program for the project.

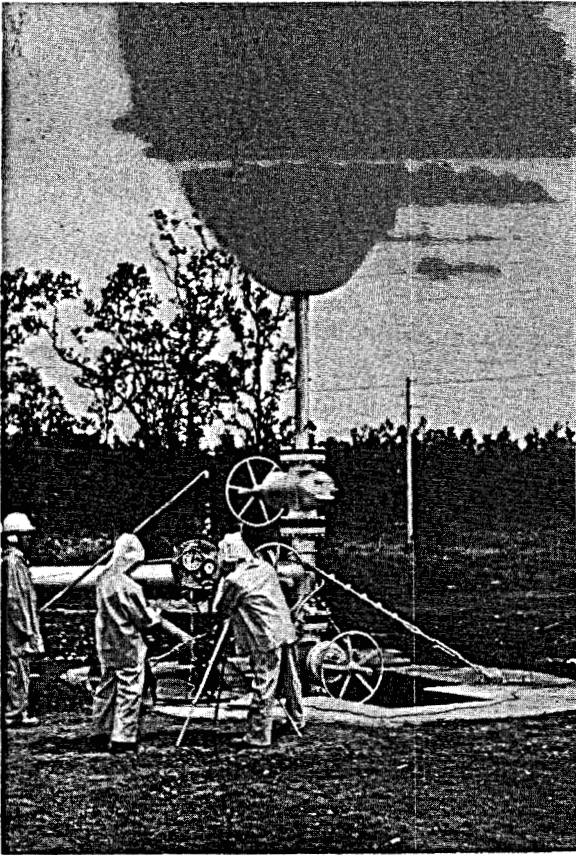
"HGP-A," for Abbott, in posthumous recognition of his major contributions to the project. Gordon Macdonald, who died after the drilling phase was completed, also deserves special recognition.

HGP-A's initial public flashing on July 2, 1976, is one of the historic moments of renewable energy development in Hawaii. Although it was recognized that the bottomhole temperature of 676°F made HGP-A one of the hottest geothermal wells in the world, the tremendous surge of geothermal power released during the four-hour flow test—with a roar equivalent to that of a 747 jet at takeoff—caught the researchers by surprise. Subsequent well testing revealed that the pressure, temperature, and flow rates of the geothermal fluids were sufficient to produce electricity.

The next logical step was to install a turbo-generator to obtain further data on the characteristics and extent of the geothermal resource and to demonstrate the feasibility of geothermal energy utilization. The wellhead generator phase of the project was funded in June 1978 by USDOE with additional support from the State, the university, the County of Hawaii, and Hawaii Electric Light Co. (HELCO) for the design, construction, operation, and maintenance of a geothermal electric 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 electric power from Hawaii's geothermal resource was produced the next month, making Hawaii the second state to generate electricity from its geothermal resources. Following an extended shakedown period, commercial operation began early in 1982, and as of December 30, 1984, HGP-A had produced 53,785,408 kWh for the Big Island's utility grid.

The success of HGP-A encouraged further development of the state's geothermal resources. Other sites were tested for possible activity, and a four-year geothermal resource assessment program was begun in 1978 under the direction of Charles Helsley and Donald Thomas of the Hawaii Institute of Geophysics.

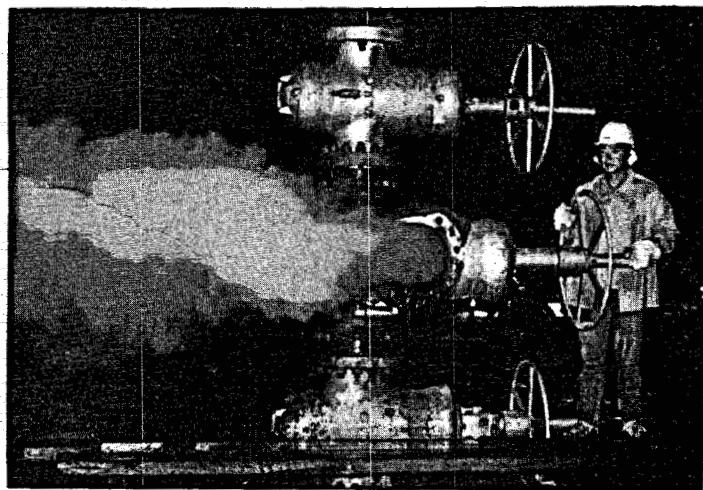
Photo: John W. Shupe



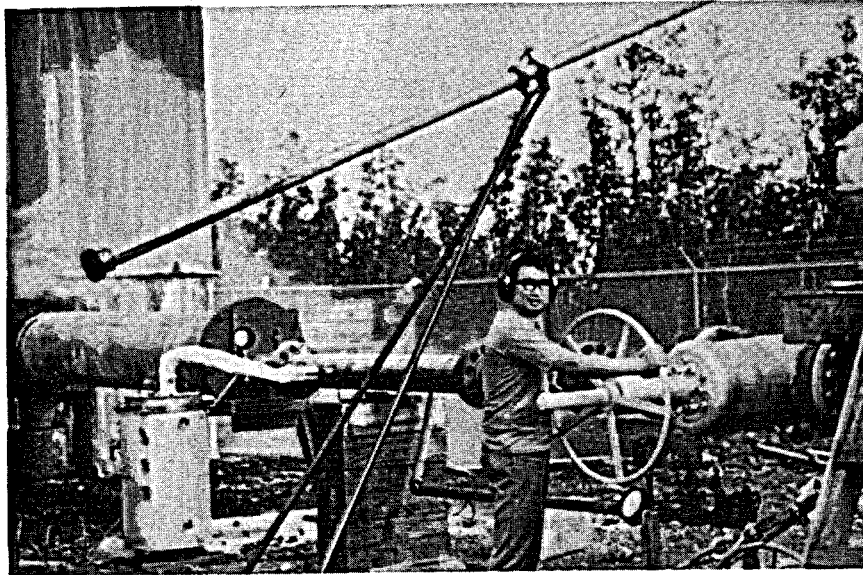
The July 1976 historic flashing of the HGP-A geothermal well with (left to right) Warwick Tracy, Deane Kihara, and Art Seki.

Assessments were made through a compilation and evaluation of existing geological, geochemical, and geophysical data for the Hawaiian Islands. Tests on seismic activity, electric and magnetic properties, and gravity were conducted to obtain additional information, as necessary. Twenty separate geothermal areas were identified as having potential for either a high- or low-temperature resource and were categorized according to probability of development. Other assessments were made of market conditions, legal rights, relationship to populated areas, environmental effects, land ownership, industrial power demand, and the cost and feasibility of electric transmission.

Private interests have been encouraged to invest in geothermal development in Hawaii with the success of HGP-A, the availability of information from the geothermal resource assessment, and requests from HELCO and Maui Electric for proposals to produce electricity. Development is being directed by three consortia, and Hawaii's first successful geothermal well drilled entirely with private capital was tested in October 1981. Additional private exploratory wells have been drilled in the Puna area, with reported bottom-hole temperatures well within the range for generating electric power.

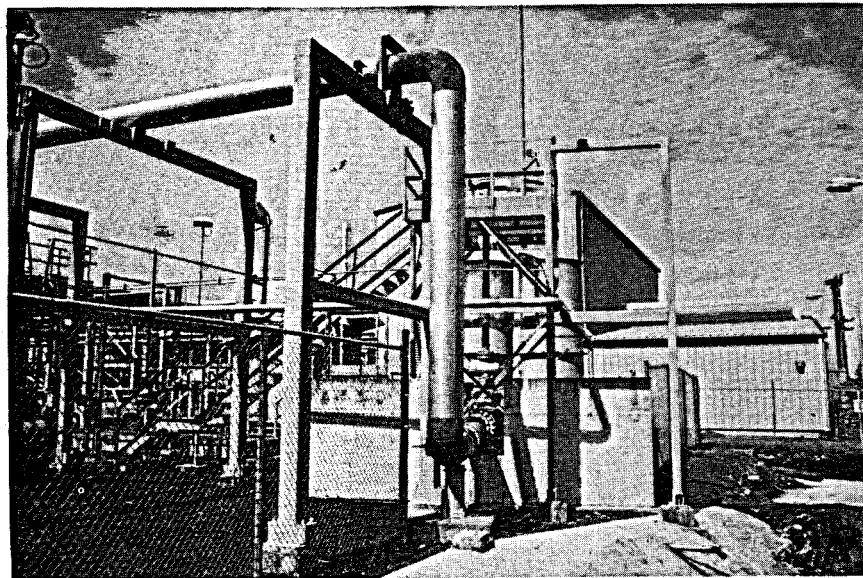


Art Seki opening the valve, discharging steam from the well to determine fluid parameters such as pressure, temperature, chemistry, and flow rates.



Bill Chen preparing to close the valve during a flow test.

Bill Chen coordinated interference tests from 1981 to 1983 between HGP-A and two nearby private wells to see whether the same hydrothermal reservoir was being tapped by all three wells. Evaluating data from past flow tests and monitoring pressure changes among the wells helped to identify characteristics of the reservoir, estimate size and storage capacity, and predict the energy potential. Yuen and Helsley in 1981 collected and synthesized the literature on the Kapoho reservoir in order to produce a reservoir model. Extrapolations from the model and various tests and assessments have led to estimations that the entire East Rift Zone of Kilauea might be a large, hot reservoir and other such reservoirs might exist elsewhere in the state.



A view of the HGP-A wellhead generator power plant.

GEOTHERMAL RESEARCH PROJECTS

Then HNEI director, John Shupe, spearheaded the HGP-A project. HNEI has also played a crucial role in supporting geothermal energy development by funding basic geochemical and geophysical studies of fluids and surrounding rocks and soil, as well as technology experiments and environmental investigations.

Hawaii's hydrothermal systems emit both steam and hot water. A study by Ping Cheng on two-phase heat transfer mechanisms attempted to develop a method for predicting sizes of vapor zones around hot magma bodies and rates of heat transfer through them. Results should facilitate estimations of energy extraction rates and, therefore, the production lifetimes of geothermal reservoirs. A number of other projects examined groundwater and geothermal fluids. Such studies help to determine the character and extent of a known geothermal source and the location of other potential geothermal sources, or even fresh groundwater.

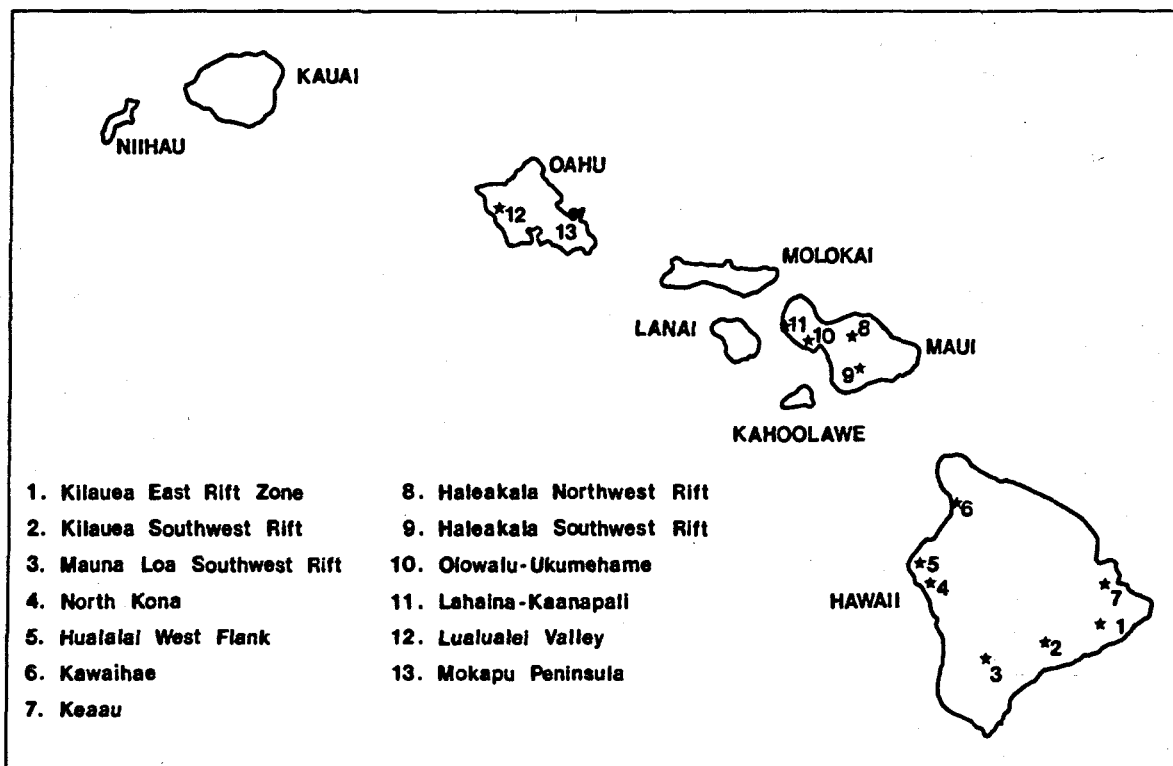
Researchers from the Hawaii Institute of Geophysics have investigated groundwater chemistry, temperatures, and movement in water wells and springs on Kilauea's East Rift Zone to determine how underground plumbing affects heat transfer in the rift zone and, thus, the longevity of the geothermal resource. Work by David Epp and his team included collecting and evaluating data on the time that groundwater takes to move into and out of the rift zone; the effects, if any, that testing and production at HGP-A have on groundwater levels; and the temporal and spatial distribution of discharges from HGP-A. The researchers are now numerically modeling the hydrology of the rift zone based on this data.

Gary McMurtry attempted to gain a better understanding of the hydrology and biology, especially microbiology, associated with geothermal systems in submarine rift zones. His project used submersibles to study undersea fresh water from hydrothermal vents.

Donald Thomas has worked on the geochemistry of groundwater and geothermal fluids in a monitoring study of HGP-A and in a resource assessment of West Maui. He designed an improved downhole water sampler, a mechanism that can take water samples effectively and efficiently from different depths of the well in order to test the water chemistry. He also undertook a project to evaluate the abundance patterns of inert gases in geothermal fluids as a means of predicting the quality of a geothermal resource after a well is drilled. In another project he analyzed sodium/lithium ratios in HGP-A unflushed brines to see if they could serve as a geothermometer to estimate the temperatures of underground reservoirs before a well is drilled. Thomas currently serves as the direct university link to HGP-A.

Geophysical techniques used in the exploration for geothermal energy resources include electric and electromagnetic soundings, and heat flow and seismic measurements. The goal of detecting and interpreting anomalies requires a thorough knowledge of the physical, seismic, and electrical properties of rocks in their natural state. Murli Manghnani evaluated the normal electrical conductivity properties of certain rocks under various temperatures and pressures to locate magma chambers. He then began an acoustic evaluation, sending sound waves through basalt samples under laboratory conditions that simulated realistic geothermal environments along the parameters of fluid content, temperature, and pressure. This project is ongoing and should prove useful in locating and delineating underground magma chambers.

Core samples collected during drilling of HGP-A were studied in another way by Hsueh-Wen Yeh. Because heat and fluids in a geothermal reservoir alter the chemistry of rocks, careful examination of the chemical compositions of HGP-A cores gives information about temperatures in the reservoir, as well as sources of the fluid. Knowing the thermal history and subsurface fluid circulation patterns of the reservoir makes it possible to estimate the economic value of the resource.



Field study sites for Hawaii geothermal resource assessment.

Technology Development

In the conversion of natural energy sources to readily usable energy, many systems under consideration today are limited by the effectiveness of heat transfer components, that is, those parts of the generating system that are used to transfer energy from the heat source to the working fluid. Design data for heat exchangers generally are limited to simple shapes and configurations. An early HNEI study by Deane Kihara was intended to determine the effective heat transfer rate in multiple element heat exchangers. Two other projects investigated direct tapping of subsurface magma sources for energy to circumvent the need for hydrothermal systems. For this purpose David Muenow carried out mass-spectrometric studies of the reactivity of liquid magma to potential heat exchanger materials. Jorn Larsen-Basse and Ko Moe Htun completed work to determine which alloys might be most efficient for direct-contact heat exchangers. They exposed various metals to fumarole-type gases in order to find the medium that not only conducts heat, but is also strong enough to withstand corrosive gases. Larsen-Basse, whose studies of materials problems have been funded by HNEI since 1975, is currently investigating the effects of HGP-A geothermal brines on various metals and alloys to be used in heat exchangers. He is also examining the corrosive effects of Hawaii's humidity, temperature, and atmospheric salt content.

Environmental Assessments

A major concern in any energy development project is its effect on the environment. Several problems may appear in the development of a geothermal energy reservoir: the emission of gases, the disposal of large volumes of hydrothermal fluids, and the possible effect of volcanic activity on a power plant built in an active rift zone. Therefore, it is important for environmental baseline studies to be undertaken before development begins. For HGP-A, extensive monitoring and testing took place early in the operation.

The environmental monitoring program supervised by Sanford and Barbara Siegel has showed HGP-A to be one of the cleanest geothermal wells in the world. The Siegels' ongoing field investigations include sampling of the air, water, soil, and vegetation to discover whether changes occurring in the environment are caused by the presence of the geothermal well fluids. The Siegels determine the emissions of mercury, arsenic, and other heavy metals, as well as the presence of sulfur dioxide, sulfuric acid, and hydrogen sulfide. In environmental assessments, measurements of the cumulative effects of all pollutants is as important as the individual effect of each. The Siegels' findings show that the impact of HGP-A does not appear to be harmful. In the case of hydrogen sulfide, a particular local concern, the Hawaiian Electric Company has funded a project by the Siegels to study the affect on people living within active geothermal sites in Rotorua, New Zealand. In their preliminary report, it was concluded that although the quantities of hydrogen sulfide in the air around Rotorua were much greater than at HGP-A, there seemed to be no deleterious effect on the overall health of Rotorua's citizens or their death rates. Sanford Siegel undertook another study to determine the sensitivity of key Hawaiian native plant species to discharged geothermal fluids. His findings will influence waste management practices and monitoring standards.

An important consideration in monitoring HGP-A is Kilauea Volcano itself. Volcanic activity can greatly affect the environmental measurements at the well site, which is in the East Rift Zone of the volcano. Indications of contamination in the air have been noted, but this occurs even when the well has been shut down for long periods. Toxic gases produced by Kilauea Volcano can have significant effects on the environment at Puna. HNEI is currently funding an investigation by David Karl on biological control of sulfides from the gaseous emissions.

THE FUTURE OF GEOTHERMAL DEVELOPMENT IN HAWAII

HGP-A is the hottest well in the United States, and the entire East Rift Zone of Kilauea may be a large hot reservoir with high energy potential. However, despite the success of HGP-A and the state's support for geothermal development, the lack of a major market for electrical energy on the Big Island, as well as public controversy and uncertainty about the impacts of geothermal development in a rural setting, have substantially hampered privately funded efforts to develop the resources. The experience gained at HGP-A and the findings of current geothermal studies by Donald Thomas



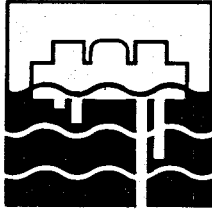
Don Thomas speaking to the University of Hawaii Foundation's Presidents Club during a May 1983 tour of HGP-A.

and other researchers should help to reduce technical uncertainties and overcome most of the public's concerns. Environmental studies generally have shown the relatively benign nature of geothermal energy. One such study now in progress is an evaluation of the hydrogen sulfide abatement systems installed at HGP-A. The dynamics of community involvement in decision-making are also being investigated and educational outreach programs have been undertaken.

The decline and stabilization of oil prices have discouraged large investments in most new energy technologies. However, consideration of long-term benefits over the total life cycle of a project could sway the decision-making process. The future of commercial geothermal development in Hawaii depends on: (1) the price of oil; (2) finding nonelectrical uses for geothermal energy to make geothermal plants economically attractive to developers, related industries, and the community; and (3) development of transportable forms of fuel, such as hydrogen or methanol, or construction of the proposed submarine cable to connect the Big Island with Oahu. In the latter case, the Hawaii Deep Water Electrical Transmission Cable Program is intended to determine the technical and economic feasibility of designing, manufacturing, deploying, and repairing an interisland deep water cable. A design has been selected, and technical, environmental, and materials studies are under way. Depending on the results of the feasibility study, efforts to finance the cable may be initiated. The next commercial phase of geothermal energy development, a power plant in the 25-MW range, awaits decisions by HELCO and private energy development companies.

The success of HGP-A has spurred interest in establishing a high technology research facility and industrial park in the Puna area. The state has provided DPED with funds to build the Puna Geothermal Research Facility (PGRF), and HNEI will coordinate the research program. The effort will cover basic research, as well as projects which are closer to the marketplace of interest to the local community. The Puna facility will focus on electricity-based applications of geothermal energy, such as hydrogen fuel and fertilizer production, as well as nonelectrical applications, for example, agricultural processing, aquaculture, and health spas. By-products recovery—sulfur, silica, carbon dioxide, helium—and biomass conversion to liquid fuel using geothermal heat and electricity are other promising areas for research.

PGRF will attempt to attract federal, state, county, and private funds to support research that will be of value to the people living in the area. Thus, the geothermal research and development program will assist in bringing a potentially major energy resource to commercial reality in a manner that is compatible with the needs of the region.



OCEAN ENERGY RESEARCH

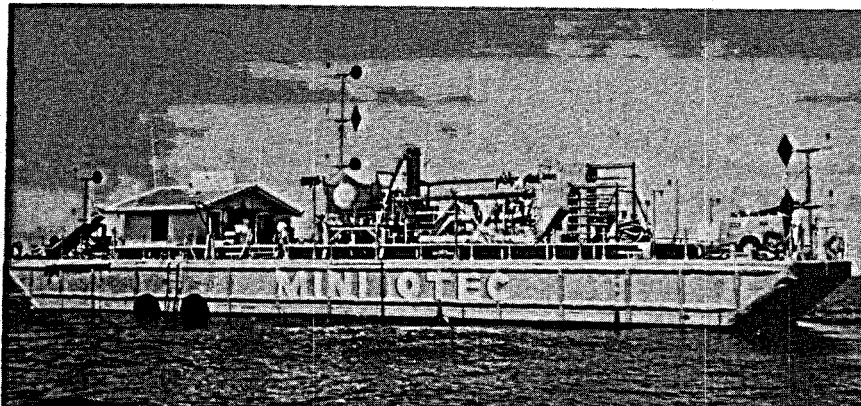
TEN-YEAR HISTORY

INTRODUCTION

The tropical ocean surrounding Hawaii provides a promising renewable energy option—ocean thermal energy conversion, or OTEC. The U.S. Department of Energy (USDOE) OTEC program in Hawaii has focused on: (1) a proof-of-concept experiment to demonstrate the technical and economic feasibility of OTEC power on a relatively large scale, which could culminate in building the world's first major OTEC plant off Oahu and (2) basic research at NELH on open and closed cycle OTEC processes, and possible by-products, such as fresh water and aquaculture. The State of Hawaii has also made a substantial investment in OTEC research, with state funds primarily used to build up the Natural Energy Laboratory of Hawaii (NELH) on the Big Island and to supplement the major federal programs that have taken place there. HNEI has been involved in state and federal OTEC efforts by providing seed money to individual research and engineering/design projects.

Two main types of OTEC heat engines have been studied. First proposed in 1881 by Jacques d'Arsonval, the closed cycle OTEC system has been the major focus of federally funded research. It is now a technically feasible process under engineering design for possible construction at a 40-MW scale off Kahe Point on Oahu. In closed cycle OTEC, a pressurized working fluid, such as ammonia, is vaporized with warm ocean water to run a turbine-generator, and is then condensed with cold deep ocean water to begin the cycle again. Compared to open cycle systems, the closed cycle process can use relatively smaller turbines. On the other hand, they require very large heat exchangers, extra power for the working fluid subsystem, and biofouling and corrosion controls to maintain optimum heat transfer rates.

The first open cycle OTEC experiments were conducted in the 1930s by Georges Claude, a student of d'Arsonval. This method uses seawater itself as the working fluid. Warm surface water is evaporated in a vacuum, producing low-pressure steam. The steam is then expanded in a very large turbine to produce electricity, and is finally condensed back to a liquid using deep cold ocean water.



Mini-OTEC was the first modern test of a complete closed cycle OTEC system; its success proved the OTEC concept and provided experience in design, fabrication, deployment, and operation of an OTEC system.

The advantages of open cycle systems are that fresh water can be produced from the condensed steam; heat from warm seawater does not need to be transferred to a second working fluid, so efficiencies may be higher and costs lower; and biofouling and corrosion problems associated with closed cycle heat exchangers may be minimized in open cycle systems. However, open cycle systems also require very large steam turbines, removal of dissolved gases deaerated from seawater, and pumps to maintain vacuum conditions.

Several types of OTEC systems are being studied for different sites and situations. OTEC facilities may be shore-based, tower-mounted offshore, moored, or designed to graze in the open ocean. Depending on system design, a variety of products and applications may be coordinated: electricity, fresh water, aquaculture using cold nutrient-rich seawater, hydrogen and oxygen from electrolyzed water, ammonia from this hydrogen and atmospheric nitrogen, methane or methanol using a carbon source and OTEC energy, and refined metals processed from ores brought to the OTEC plant. OTEC promises to be a truly versatile energy resource if remaining technical problems can be identified and remedied, and the economics are improved.

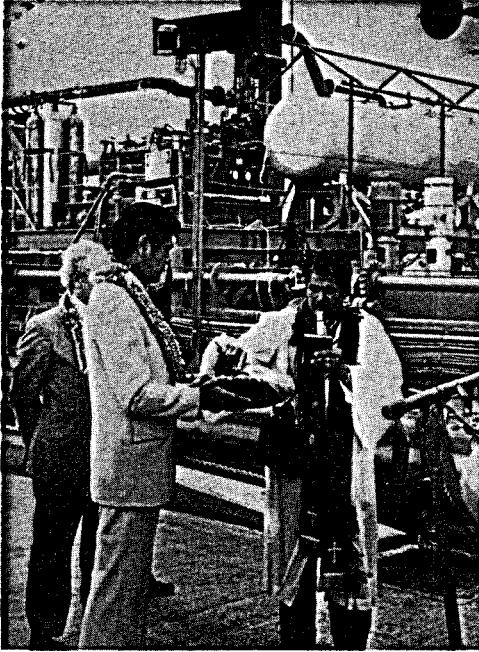
OTEC plants were at first projected to be very large: a 400-MW plant, for example, with a platform the size of an aircraft carrier deck; a 100-foot diameter, 3,000-foot long cold water pipe; and a water flow per day of 45 million gallons—the average daily discharge of the Nile River. Large capital outlays have shifted interest in OTEC energy to smaller plants in the range of 10-MW that would be suitable for areas where energy costs are highest, such as island communities. OTEC could benefit these isolated island economies by providing electricity and useful by-products.

MAJOR OTEC PROGRAMS IN HAWAII

In 1978 there was no general agreement that a closed cycle OTEC plant could actually generate net positive electrical power. Therefore, Mini-OTEC, the world's first operational closed cycle, at-sea plant, was constructed and deployed as a combined effort of the State of Hawaii, Dillingham Corporation, and Lockheed Missiles and Space Company. A Navy barge retrofitted with a power plant and cold water pipe, Mini-OTEC, operated for six months moored in 3,000 feet of water about 1.5 miles offshore of Ke-ahole Point on the Big Island. Mini-OTEC proved the practicality of the OTEC principle by producing 10-15 kilowatts of net power from more than 50 kilowatts of total power, and yielded valuable operational data. Its remarkable success catalyzed worldwide interest in OTEC.

Contracts for USDOE's OTEC-1 project were awarded in 1978 to convert a Navy tanker into an ocean test facility for a 1-MW OTEC system. In October 1980 the *S.S. Ocean Energy Converter* was deployed in waters 4,600 feet deep, 18 miles northwest of Ke-ahole Point. A 2,150-foot, 48-inch diameter polyethylene cold water pipe was deployed and attached to the ship at sea. Heat exchangers, a working fluid system, and cleaning techniques for biofouling and corrosion were tested.

Federal budget cuts terminated the OTEC-1 program in April 1981. Nevertheless, OTEC-1 has continued to be useful. Its heat exchanger components and computer systems were placed at NELH, providing equipment for process and materials research. Funds from scrapping the ship have been made available for renewable energy research programs in Hawaii.



Governor George Ariyoshi assists Reverend Abraham Akaka with official blessing of Mini-OTEC in May 1979.



July 5, 1980 marked the dedication ceremony for the S.S. Ocean Energy Converter, an ocean-going facility designed to obtain operational data on the components of a 1-MW OTEC system.

Natural Energy Laboratory of Hawaii

In 1974 the Hawaii State Legislature set aside over 300 acres of state-owned land at Ke-ahole Point on the Big Island of Hawaii for research on OTEC, aquaculture, solar ponds, direct solar applications, and other renewable energy resources. The easy access to deep cold water provided by the steep offshore slopes, high solar insolation rates, proximity of air and sea transportation facilities, and availability of undeveloped land made the location ideal for a unique oceanographic and solar energy research facility. NELH is the only laboratory in the world continuously supplied with both warm surface and cold deep ocean water for experiments.

The state founded NELH to promote and encourage renewable energy research with the hope of attracting private and public funding to ultimately make the facility self-supporting. NELH has become a premier OTEC onshore research and development laboratory where reliable, long-range test programs on biofouling, corrosion, and component performance are conducted. A 12-inch cold water pipe (CWP), installed in 1981, brings cold water from a depth of 2,000 feet at the rate of 350 gallons per minute (gpm), and two warm water pipes bring in 2,000 gpm from 15 feet offshore. Future plans for NELH include the installation of a larger, more permanent seawater supply system for both warm and cold water. Plans to install the OTEC-1 48-inch pipe at NELH failed in 1983 when a portion of the pipe was lost in the towing process. However, with the recent opening of a 20-acre commercial demonstration module for abalone production using deep cold ocean water and expanded OTEC experiments, a privately financed pipe system is on the drawing board, and a one-meter diameter CWP is planned, along with upgraded water intake facilities, and other improvements.

Reducing the technical risk of the CWP is critical in any OTEC design, and the size and mass of the CWP in a 40-MW plant—30 feet in diameter and 3,000 to 10,000 feet in length—present a major engineering challenge. As part of a USDOE Multiphase CWP At-Sea Test Program, Dillingham Construction Corporation has installed an 8-foot diameter CWP at NELH. For the past several years, the Hawaiian Dredging and Construction Company, a division of Dillingham, has been working on a project to design, construct, and install the pipe at sea and operate it in two configurations. The 400-foot-long pipe, one-quarter scale of the planned 40-MW plant, tested successfully when it suspended vertically from the Mini-OTEC barge, and again more recently when a section was towed to NELH and tested in a down-the-slope configuration. Measured was wave and current loading on the pipe and, in the second configuration, on the foundation, to validate analytical models for CWP design and to experiment with handling techniques for large diameter pipes.

Proposed 40-MW Power Plant

Mini-OTEC, OTEC-1, cold water pipe tests, and other work at NELH will provide necessary information for designing what could be the world's first major OTEC facility, a 40-MW closed cycle pilot plant to be located offshore of the Hawaiian Electric Kahe generating station. In February 1982 USDOE announced that it would support proposals for two closed cycle OTEC pilot plants in Hawaii: one mounted offshore and another a shore-based facility, both at Kahe Point. The consortium of Ocean Thermal Corporation, TRW, and Dillingham was awarded a subsequent USDOE contract in 1983 for engineering design of the shore-based plant. The Phase I design is now being tested against community, financial, and environmental requirements. Cost estimates must be made credible to the financial community and private funding needs to be arranged.



Waves break over cold and warm water pipes at NELH.

State funds supporting the plant design are targeted at establishing an environmental data base and assessing impacts, including possible effects on the adjacent community. Other factors that will influence design revision are the results of CWP tests and corrosion and biofouling experiments, and the progress of aquaculture enterprises developed in conjunction with the OTEC process. HNEI is spearheading many of these projects.

HNEI OTEC RESEARCH PROJECTS

HNEI's history of OTEC research is closely connected with the history of NELH. Initial development of NELH between its 1974 founding and 1978 involved a series of environmental studies and surveys leading to the procurement of permits for performing research at Ke-ahole Point.

Robert Palmer and Kaare Gundersen, through the Marine Affairs Coordinator, initiated the first studies of OTEC as a concept of significance to Hawaii. Shortly thereafter, Karl Bathen and Theodore Lee made environmental impact assessments and researched pipeline design materials and methods of installing a pipe 2,000 feet below the ocean's surface. Edward Noda conducted the initial ocean bottom survey at Ke-ahole Point in order to understand the area over which cold water pipes would be laid. Data on currents and their effects on OTEC systems were collected by Noda, Lee, and Charles Bretschneider. James Marsh made a study of OTEC's economic viability and Hu Hsien Hwang studied the feasibility of linking the islands with submarine electrical cables. Mini-OTEC was positioned in the NELH research corridor, and research projects on biofouling, corrosion, and environmental consequences were begun.

This early NELH work proved useful in 1978 when the Research Corporation of the University of Hawaii (RCUH), Carnegie-Mellon University, and the TRW Company, acting on behalf of the NELH Managing Board, proposed to USDOE the development of the Seacoast Test Facility (STF) at NELH. A detailed design was prepared to meet USDOE specifications for a shore-based research laboratory intended to complement the floating experiments planned for the OTEC-1 vessel.



Manning the shovels at the STF dedication are (from left to right) Wytze Gorter, Paul Yuen, Mayor Herbert Matayoshi, John Craven, Rep. Minoru Inaba, Glenn Oda, and Albert Yoshiyama.

Lawrence Hallanger, STF Project Manager and Interim Executive Director of NELH, supervised the construction of the USDOE facility, which included an onshore laboratory, upgraded warm and cold water pipes, and increased pumping capacity. With these installations, NELH became the primary U.S. base for OTEC research. To launch this effort, an assessment of the OTEC potential and the U.S. OTEC program was made in 1981 by Paul Yuen, assisted by experts from the university and the business community. The study included assessments of the existing natural resource, OTEC technology development, engineering problems, economics, environmental effects, legal issues, political and social concerns, and policy implications and recommendations. Research decisions for NELH and the scope and direction of the current program were made on the basis of this report.

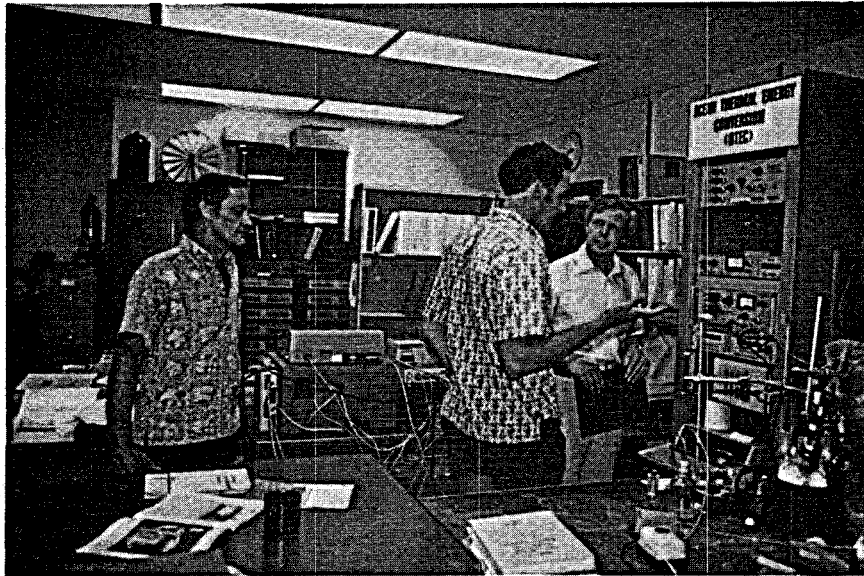
HNEI-funded research at NELH has involved the engineering and design of OTEC systems, including an open cycle, small scale simulation. Research also has continued on biofouling and corrosion experiments, environmental baseline and impact studies, and applications of OTEC energy to aquaculture and solar ponds.

Technology Development

Experimental work has concentrated on cutting costs in the system components and maximizing the system's efficiency by controlling biofouling (the accumulation of microorganisms on metal heat exchangers) and corrosion. Frederick Munchmeyer initiated some of the original field work when experiments were carried out on a buoy from 1974 to 1980. Aluminum, titanium, stainless steel, and copper-nickel tubes simulating OTEC heat exchangers were connected to the buoy, submerged 50 feet, and monitored.

During OTEC-1's short operation, the effectiveness of sponge rubber balls as a biofouling and corrosion countermeasure was tested. The balls, less than one inch in diameter, with and without abrasive coatings, were found to be a fairly reliable method of removing biofouling and corrosion from certain types of heat exchangers. Experiments by Jorn Larsen-Basse showed that extremely low levels of chlorine were able to control biofouling totally in various heat exchanger candidate materials. The long-term effects of chlorine on the marine environment are still being investigated. Patrick Takahashi and William Avery (of the Applied Physics Laboratory) have initiated a program utilizing ultraviolet irradiation and ultrasonics for antibiofouling treatment.

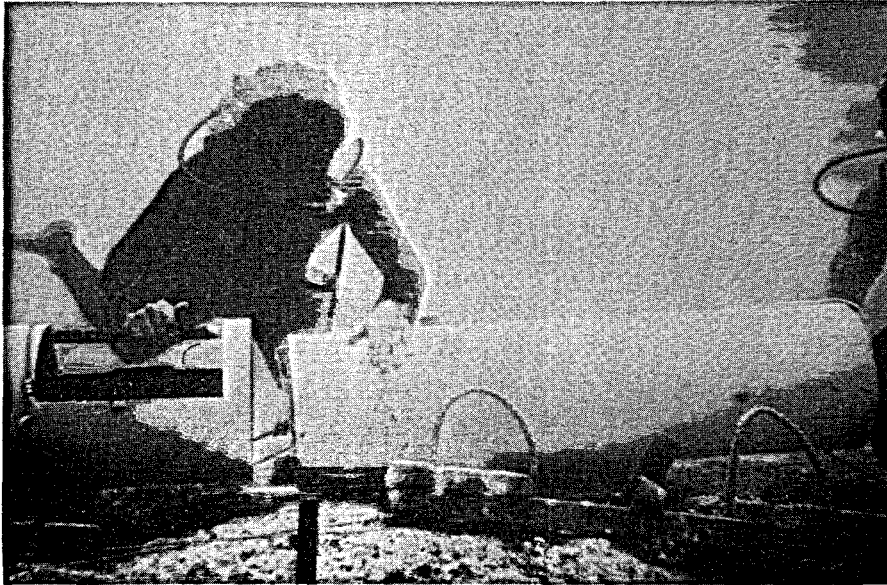
Bruce Liebert has been evaluating metals for their biofouling and corrosion resistance and for the ease of methods to clean them. Since 1978, Jorn Larsen-Basse has been investigating protection procedures that can be used to prevent metal corrosion. Initial results of biofouling and corrosion investigation indicate that aluminum, titanium, stainless steel, and copper-nickel should be the prime choices for heat exchangers in future OTEC plants. Aluminum alloys, it was found, do not pit or corrode in warm seawater; tests of these alloys in cold deep seawater are still continuing and show mixed results. Understanding the corrosion process will form a basis for the development of resistant alloys.



DOE's Earl Gjelde, right, listens as UHM Mechanical Engineering Professor Bruce Liebert explains his project on OTEC biofouling and corrosion. Left, ME Chairman Jorn Larsen-Basse, who gave Special Assistant Gjelde a tour of his department's labs, looks on.

Larsen-Basse, along with Hans Krock of J.K.K. Look Laboratory, is also performing OTEC open cycle system simulation. Under Solar Energy Research Institute (SERI) and HNEI funding, the work in open cycle has included the construction and testing of evaporator and condenser units, water/gas quality tests, and gas content experiments. Initial investigations comparing ocean water with SERI's freshwater OTEC experiments showed that foaming of seawater is not a significant problem; that boiling of seawater in a vacuum appears similar to boiling of fresh water; and that relatively high efficiencies can be obtained in both evaporator and condenser using seawater. A more comprehensive test program is being planned for the SERI-funded deaeration system used by Krock. Data from these tests will be used to design an experimental system ten times the size of the existing one.

Other research projects have simulated various components of OTEC systems and made tests in real ocean conditions. In conjunction with at-sea tests of the shelf-mounted cold water pipe on the offshore slope of NELH, Theodore Lee is developing a wave measurement system that will provide information on the strength and power of waves, which is necessary for the design of offshore OTEC plants. Robert Grace is determining CWP design requirements through his evaluation of forces exerted by breaking waves on OTEC pipes. John Craven is devising methods of using environmental forces such as wind, waves, and current to dynamically position an OTEC plant designed to "graze," or move over the ocean surface without being moored.



Robert Grace and diving assistant calibrate test pipe for horizontal wave forces.

Environmental Assessments

Since OTEC is a new technology, the environmental effects of building and operating an OTEC plant are unknown. Environmental baseline studies were made before establishing NELH and each of the major OTEC experiments conducted in Hawaii: Mini-OTEC, OTEC-1, and the 40-MW pilot plant now under design. The effects of the environment on the OTEC facility must also be determined. For example, in siting studies for NELH, bathymetry studies were made with manned submersibles before laying the cold water pipe, and measurements were made of nearshore and offshore thermal density stratification, nutrient concentrations in the water column, local nearshore benthic biota, plankton community composition and productivity, seasonal circulation patterns, and local wave, swell, and meteorological conditions throughout the year.

The temperature and chemical constituents of discharges are the most important considerations for OTEC's effect on the ocean environment. While chlorine is an effective method of controlling biofouling in heat exchangers, the compounds formed in seawater and their effects on marine life and aquaculture species have not been ascertained and are the subject of a multi-year investigation by Francis Sansone. Likewise, Satoru Taguchi is looking into the effect of OTEC cold wastewater on existing phytoplankton communities.

Applications to Improve Economics

OTEC cold water discharge has been found to have a beneficial effect for aquaculture, an important rising industry for Hawaii. Experiments at NELH have shown that a variety of marine species—salmon, rainbow trout, Maine lobster, abalone, kelp, and nori (edible seaweed)—can be grown in the cold water outfall from OTEC plants. In fact, the economic potential of some of these products may exceed or at least approach the value of the OTEC-produced energy.

A privately funded commercial demonstration project currently under way will serve to test this marriage of OTEC and aquaculture. Hawaiian Abalone Farms has experimentally grown abalone and the kelp on which they feed in OTEC cold water at NELH for two years. Based on these tests the company recently opened a \$10 million commercial module at NELH. The company is also considering installing its own cold water pipe system and supportive facilities at NELH.

Another application of the OTEC cold water discharge is a new type of solar salt pond. Funded by DPED, the proposed one-acre solar salt pond of 30 kW generating size has been designed to use NELH's cold deep seawater on the condenser side to provide a higher temperature differential than solar energy and stratified layers of salt alone, as in a traditional solar pond. If funded, construction of this "SPOTEC" (Solar Pond-OTEC) project will include 4 acres of salt evaporation ponds.

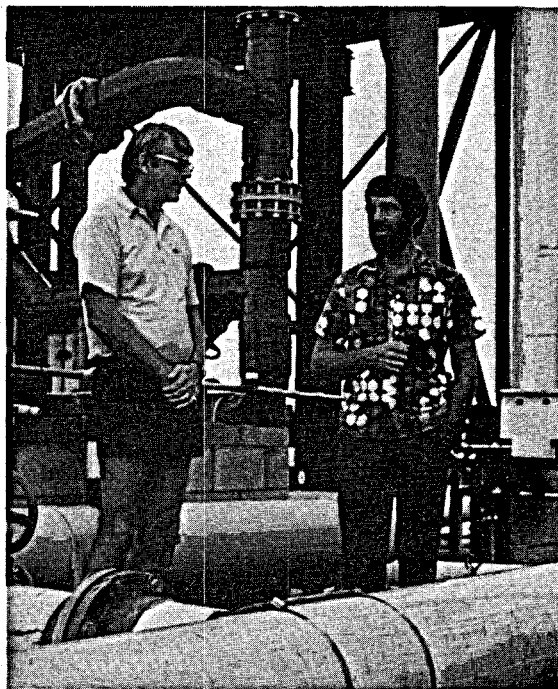
THE FUTURE OF OTEC IN HAWAII

Over the past decade in Hawaii, OTEC has developed from an interesting idea and small laboratory experiments to plans for a 40-MW facility. John Craven, director of the UHM Law of the Sea Institute, estimates that Hawaiian territorial waters could produce 10 to 15 quads (1 quad = 10^{15} Btu) of OTEC energy per year—more energy than is currently provided by annual imports of oil to the entire United States.

Key to the future of OTEC research for Hawaii and the nation is expansion of the facilities at NELH. The USDOE has shown renewed interest in supporting basic research and technology transfer in this field. Several firms are planning aquaculture projects and may be interested in contributing to capital improvements at NELH to provide adequate supplies of water not only for aquaculture, but for the OTEC open cycle and solar pond demonstrations as well.

Federal funding for the 40-MW Kahe Point pilot plant ends with completion of the design. Ocean Thermal Corporation, however, has announced its plans to go ahead with building the project, although full financing has not yet been resolved.

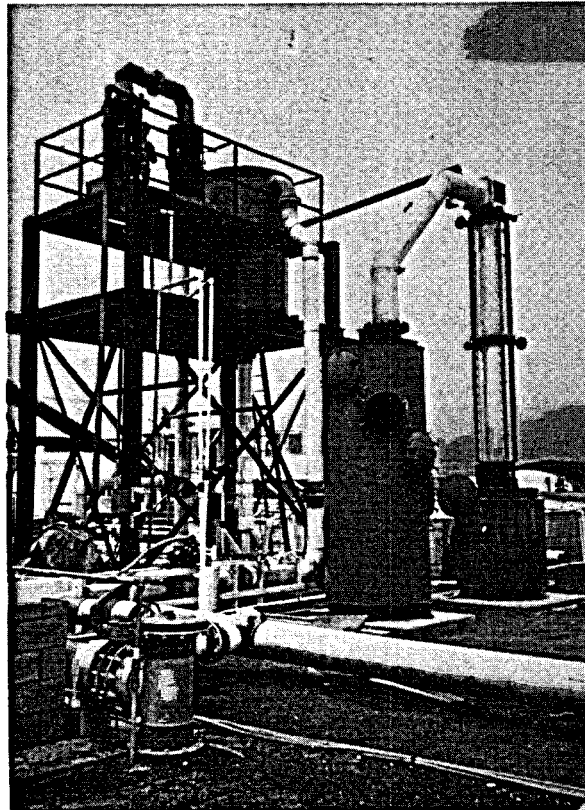
To make maximum use of the Pacific's great OTEC potential, hydrogen, ammonia, or methanol will need to be explored as supplemental products. One possibility being examined by USDOE is to use imported coal for the carbon source and hydrogen produced from OTEC-generated electricity to produce methanol. The Applied Physics Laboratory of Johns Hopkins University has completed studies showing that OTEC-produced methanol is cost-effective today.



David Block, Director of the Florida Solar Energy Center, touring OTEC facilities at NELH with Tom Daniel, NELH Laboratory Director.

OTEC's multiple possibilities make this a strategic research area for Hawaii. The Pacific International Center for High Technology Research (PICHTR) has also made OTEC a top priority, with special interest in the coproduction of fresh water to aid the development of Pacific island nations. The Fellows in Renewable Energy Engineering (FREE) program is seeking an ocean energy specialist to assist the OTEC research and development effort for the university and the state.

Given appropriate research funds, OTEC could become a major source of reliable power and products for domestic use and export. Anticipating future needs, HNEI will continue to support R&D at the cutting edge of knowledge.



Open cycle OTEC experiment apparatus (upper left) mounted on cold water header tank tower at NELH.



SOLAR ENERGY RESEARCH

TEN-YEAR HISTORY

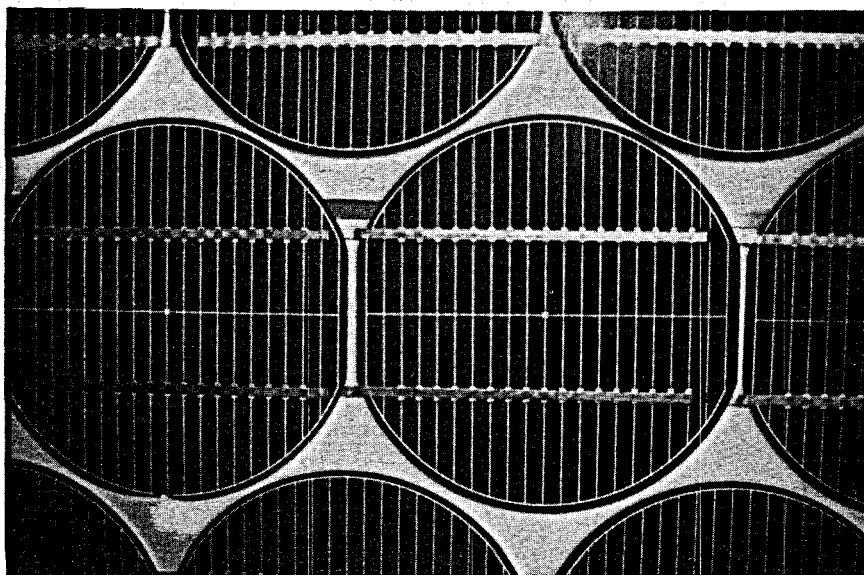
INTRODUCTION

On an annual basis, the amount of solar energy that reaches the surface of the earth is about 14,000 times greater than the fossil energy consumed. In Hawaii the ratio of solar to fossil energy is even greater because of higher than average local insolation rates. Solar energy may be converted to usable forms either directly, by means of solar thermal or electrical systems, or indirectly, by means of intermediate solar energy forms—biomass, hydroelectric power, ocean thermal energy conversion, and wind.

Direct conversion techniques are numerous, of varying complexity levels, and in various developmental stages. Two basic categories of direct solar use are being developed or are in use in Hawaii: photovoltaic cells, which convert the sun's energy directly into electricity, and solar thermal systems, which collect the sun's heat and use it for heating or cooling systems or to produce electricity. Prototypes, demonstration models, and commercial systems of these technologies are operating in Hawaii.

SOLAR ENERGY DEVELOPMENTS IN HAWAII

Perhaps the most ingenious of new solar technologies is the photovoltaic (PV) cell which consists of a silicon wafer crisscrossed by a grid of metal contacts. When photons of sunlight strike the cell, they free electrons that migrate to the contacts and produce direct current electricity. PV cells can be used in flat arrays, or placed at focal points of concentrating systems to increase their production.



Sunlight is converted directly into electricity in this single-crystal silicon photovoltaic array. Each cell is approximately 4 inches in diameter and produces approximately one watt.

PV cells were first used on spacecraft in 1958 and later on earth to power radios and instruments in remote areas. Major engineering advances over the past ten years have led to efficiency increases and relative cost reductions that have made PVs commercially feasible, although at costs much higher than conventional energy technologies. Beginning in the mid-1970s PVs came into limited use producing AC power for isolated residences.

With the latest technology, \$5,000 per installed kilowatt is a current cost figure for silicon-cell generation systems. However, in addition to improvements in the basic single-crystal silicon cells now in use, new ribbon, polycrystalline, multi-layer, and thin film amorphous cells are becoming available. These improvements should lower the cost of silicon collectors to make the systems more competitive in the future. Another promising development, involving special high-temperature PV cells for concentrator systems, is still in the research stage, but also promises to be a cost-saving advancement.

PV cells today cost a fraction of their 1974 price, with an estimated 600 small, privately financed systems operating in Hawaii. Pioneering PV demonstration projects have been funded by USDOE, DPED, and HNEI, in grid-connected lived-in residences, stand-alone systems, and a combination system using photovoltaics and solar thermal with a concentrating parabolic collector. Basic research is also being done in Hawaii on ridged-grid solar PV cells and thermal cells.

The other major application for solar energy is in solar thermal systems, which can be roughly divided into high-temperature and low-temperature heat collection. Low-temperature solar thermal systems are already proven and cost-effective in Hawaii in the form of solar hot-water systems. These systems commonly use flat-plate collectors which are fuel savers that use both diffuse and direct sunlight. Domestic water heating benefited from early projects at HNEI directed toward optimizing flat-plate collectors and their installation and operation in the Hawaii environment. In addition, insolation data were gathered and the necessary information compiled and published by HNEI in cooperation with DPED to support the effective use of solar water heaters in appropriate areas of the state. Aided by this information, tax credits, and improved technology, utilization of solar water heaters in Hawaii has increased steadily, with more than 30,000 residential systems installed—the highest number per capita of any state.

Solar ponds are low-temperature solar thermal systems that can produce sufficient thermal energy for electrical generation or process heat. Solar ponds retain the sun's heat in layers of water or other liquids that are increasingly salty with depth; the densest, most saline layer on the bottom stores solar energy. Heat is removed from the bottom layer before it boils and mixes with the upper layers, therefore, the pond is an effective solar energy converter with very little convective heat loss. The transferred heat may be used to produce electricity or used directly as process heat. Surface temperatures in these ponds under summer conditions can be 80–85°F, with bottom temperatures reaching 200°F. Year-round temperature conditions in Hawaii make it ideal for solar pond applications. Projects in Hawaii have experimented with various liquid layers and pond cleansing techniques.

High-temperature solar thermal applications require focusing collectors that track the sun and receive its direct radiation, which is necessary to achieve the 700°F or more needed for an efficient thermal power plant cycle. Solar thermal electric systems promise to be commercially viable in the not-too-distant future. A solar power tower uses an array of mirrors, or heliostats, to create high temperatures by directing solar energy to the tower apex, where the heat is stored in molten salt,

then used to produce steam from water to drive a turbine generator. Another type of solar concentrator uses tracking lenses in troughs or dishes to concentrate energy to a heat engine such as a Rankine engine. Development of solar thermal and other concentrator systems has proceeded slowly, with one concentrating PV thermal demonstration installed in Hawaii. A 100-kW parabolic dish experiment has been announced for installation on Molokai.

Solar Thermal Research

Over the past few years, a few solar thermal electric systems have been studied for specific island locations and applications. The Molokai small-community solar thermal power experiment will use four parabolic dish concentrator modules that focus sunlight to an electricity-producing engine at the focus of each dish. HNEI participated in securing needed direct insolation data for the site selection and will assist in monitoring system performance.

Another solar thermal study and preliminary design was completed by Amfac Inc. on the economic feasibility of installing a solar power tower at the Pioneer Sugar Plantation Mill in Lahaina, Maui. The system under study consisted of 1,050 heliostats directing sunlight to a 300- to 400-foot tower. A variation of this configuration was the subject of a study by C. Brewer & Co.'s Hilo Coast Processing Company. This particular system consisted of a series of parabolic mirrored collectors directing sunlight to a pipe containing a heat transfer medium which turned water to steam. The steam would have been used as process heat, but, as in the Pioneer Mill case, the system was not found economically feasible given present conditions.

HNEI SOLAR ENERGY PROJECTS

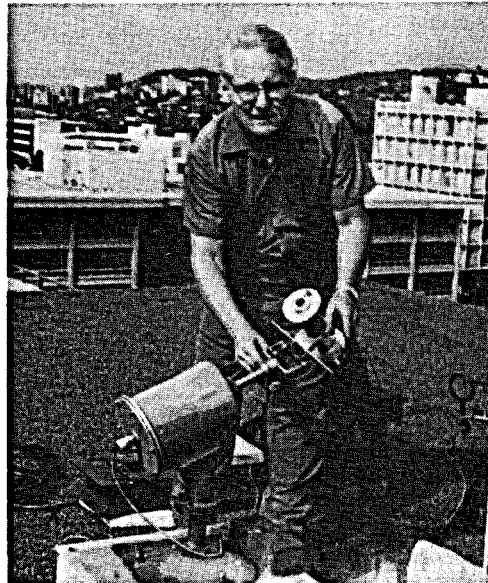
HNEI has supported 18 direct solar research, development, and demonstration projects totaling \$2,111,816, the federal portion of which was \$1,312,127. HNEI is also monitoring specific sites for the planned USDOE-funded \$4 million parabolic dish solar thermal electric system on Molokai. HNEI's most successful project has been its three residential rooftop PV systems on lived-in units interconnected to the local utility. Other HNEI work has been in basic research on collectors, PV cells, and corrosion protection.

Solar Resource Assessment

Solar heat energy is abundant and reliable in Hawaii compared with more northern climates; however, knowledge of the solar resource is fundamental to utilizing it effectively. Honolulu receives an annual average of 1,915 Btu per square foot per day (6.03 kWh per square meter per day), whereas the national average is about 1,500 Btu per square foot per day (4.73 kWh per square meter per day). Hawaii's semitropical location—the principal islands range in latitude from 19° to 22°15'N—gives the state a maximum clear-day solar insolation no higher than some parts of the mainland, but with a great deal less seasonal variation, providing an excellent annual insolation rate.

Hawaii was one of fifteen USDOE Solar Energy Meteorological Research Sites from 1978 to 1983. Under a \$1 million grant to the UHM Department of Meteorology, the existing solar radiation and meteorological network was modified and expanded to collect data that would permit the solar energy potential and its annual and diurnal variations to be estimated at any point in the islands. Colin Ramage of UHM-Meteorology and Paul Ekern of the UHM Water Resources Research Center mapped the global and direct solar insolation for the state. Ekern, with initial assistance from Takeshi Yoshihara, measured global, direct beam, diffuse beam, and ultraviolet radiation at two key sites: UH Manoa and UH Hilo.

Paul Ekern, on the roof of Holmes Hall, shows a solar radiation measurement device which utilizes a silicon cell.



The objective of these extensive studies was to supply the scientific parameters for the design of solar energy systems. At one time an effort was made to correlate solar insolation with rainfall, since there is much more data for the latter than the former; however, little correlation was found. Clouds can reflect, as well as screen, the sun so that even on a completely overcast day, the diffused insolation may amount to 30 percent of the theoretical clear-day value. Historic data collected for 50 years by the Hawaiian Sugar Planters' Association (HSPA)—both solar insolation and rainfall—have been used for computerized analyses of hourly and daily variations. This type of analysis has been extended to other stations and for other periods of time.

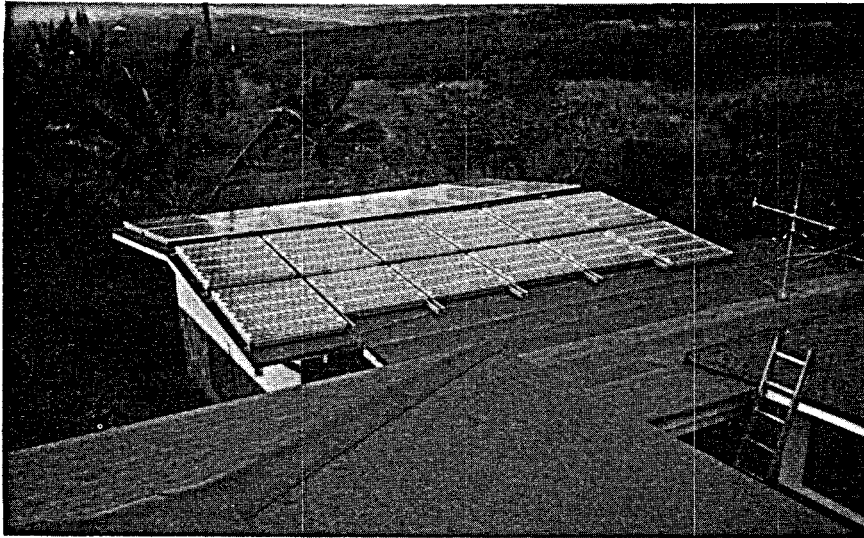
Pyranometer, pyrheliometer, UV sensor, and recorders have been installed on the roof of Holmes Hall on the Manoa campus, where data collection has been carried out for the past ten years. Coupled with the records from a nearby, now defunct, HSPA site in Makiki, Holmes Hall serves as a base reference station for Hawaii. Other instrumented sites covering the entire state have been added to the network. Special equipment was installed in some areas to measure the diffuse and direct components of solar radiation separately from the total insolation. Each component is applicable to different types of solar energy systems. Ultraviolet (UV) radiation also has effects on solar system performance and materials, and is especially intense in Hawaii.

The measurement programs were initially administered by the UHM Department of Meteorology and the Water Resources Research Center. More recently, they have come under HNEI's purview, often in direct support of USDOE projects. One example was a joint program for monitoring insolation on nine Pacific Islands.

Hawaii's solar data collection and evaluation effort has become increasingly sophisticated, and has begun to concentrate on measurement of direct insolation and its characteristics in different seasons and locations. HNEI has been awarded contracts by Sandia National Laboratories to provide specific data and analyses for selection and documentation of sites on Molokai for the planned USDOE solar-dish project. Technical assistance has been provided by the UHM Department of Meteorology and the Water Resources Research Center. The data are also provided to DPED to improve insolation maps of the islands that are used for predicting water heater performance and other similar purposes.

Residential PV Houses

HNEI pioneered the first demonstration of lived-in residences in the United States to be retrofitted with rooftop PV cells and interconnected with the utility. Funded primarily by USDOE through MIT Lincoln Laboratory and later Sandia National Laboratories, and in operation since 1981, HNEI supervised the installation of the three systems, maintained and upgraded them, and collected and analyzed the data. The project was a cooperative effort of USDOE, HNEI, ARCO Solar, Hawaii Housing Authority, Hawaiian Electric Company, and Molokai Electric Company. Paul Yuen was principal investigator for most of the life of the project, and was assisted by Art Seki and George Curtis. The experiment tested glass-enclosed, state-of-the-art solar panels, each consisting of 35 four-inch silicon cells, mounted atop residences on the islands of Oahu and Molokai. They are broadly representative of Hawaii housing: a two-story duplex in Kalihi near downtown Honolulu, a quadraplex in a new public housing area in Pearl City, and a forty-year-old ranch house on Hawaiian Homestead land on Molokai.



Photovoltaic system on Henry Wiebke's Molokai ranch home.

During the day, the electricity produced by the system is used by the household and any excess is fed into the local utility grid. At night or during cloudy periods the utility supplies electricity to the household. Transfers from residential electricity generated by solar to that supplied by the utility takes place automatically.

After initial start-up problems were solved, the systems were virtually trouble-free and have been on-line 96 percent of the time. The data monitoring system installed at each residence provides information on the electrical current produced. Rooftop weather stations record temperature, wind, and solar radiation data. A standard dial telephone is connected to each system and when the number is dialed from the HNEI offices, data are sent over the line and into a computer. Data are also recorded on cassettes and read out at the central computer. Monthly reports provide detailed information on insolation, power generation and usage, environmental conditions, and problems and solutions at each site.

Modifications to the Kalihi and Pearl City systems were subsequently made by installing more efficient new generation inverters which improved energy quality. The Pearl City unit was rewired to include the other three apartments in the quadraplex, making better use of the energy supply for all residents.

Although the experimental project has formally ended, HNEI staff continue to monitor the equipment and collect data. This pioneering project proved that PVs can be used to produce household electricity in real life situations, and proved their technical feasibility, operational reliability, and user satisfaction.

PV-Thermal Project on Kauai

Funded by USDOE and the State of Hawaii, designed and installed by Acurex Corporation, and supported by Kauai County and Kauai Electric, a combination parabolic concentrating photovoltaic/solar thermal system began producing electricity and hot water for Wilcox Hospital on Kauai in November 1981. The system consisted of 80 parabolic collectors which tracked the sun and concentrated sunlight on PV cells mounted on hollow pipes at the focal point of the collectors. Water passing through the hollow pipes cooled the PV cells and transferred the excess heat through a heat exchanger to the hospital's hot water supply. Sandia National Laboratories monitored the project and collected data for 15 months until February 1983.

The data were useful in identifying the causes of some of the problems encountered during the project. The system's performance level was lower than predicted, operating at only 50 percent of calculated values. The primary problem was that the parabolic concentration of sunlight turned out to be inefficient. Because concentrating systems utilize only direct incident sunlight, other problems may be explained by insolation rates experienced during the test period—the lowest rates in 50 years—and the system being located on the cloudy side of the island. Components may have experienced fatigue due to alternating expansion and contraction from changing sunlight conditions. Lack of a good seal between the PV cell and the receiver allowed moisture and microorganisms to infiltrate and damage components—a problem that might not have arisen with more sunlight and higher operating temperatures to inhibit microorganism growth.

The system was subsequently transferred to the U.S. Navy's Barking Sands Test Range on the western, sunny side of Kauai. The Navy plans to use the system's solar thermal potential primarily for water heating or space cooling.

Solar Ponds

In 1980 HNEI published a report on solar ponds by Karl Bathen. Research at HNEI has concentrated on improvements such as use of immiscible liquid layers. An experimental dual-tank system was first set up at Look Laboratory and this prototype was instrumented for a series of tests to evaluate various liquids and configurations. It appears that the liquid layer approach was a good choice for trade wind areas such as Hawaii and experiments are continuing.

Preliminary studies have been initiated on a new type of solar pond, a Cellular Floating Salt-Gradient Solar Pond Array (CFSGSPA) which consists of individual, cylindrical solar ponds that float, secured and interconnected to one another, on a calm body of water. The main focus of this study by Ph.D. candidate Dan Weeks is directed toward modeling the thermodynamic behavior of a single cell.

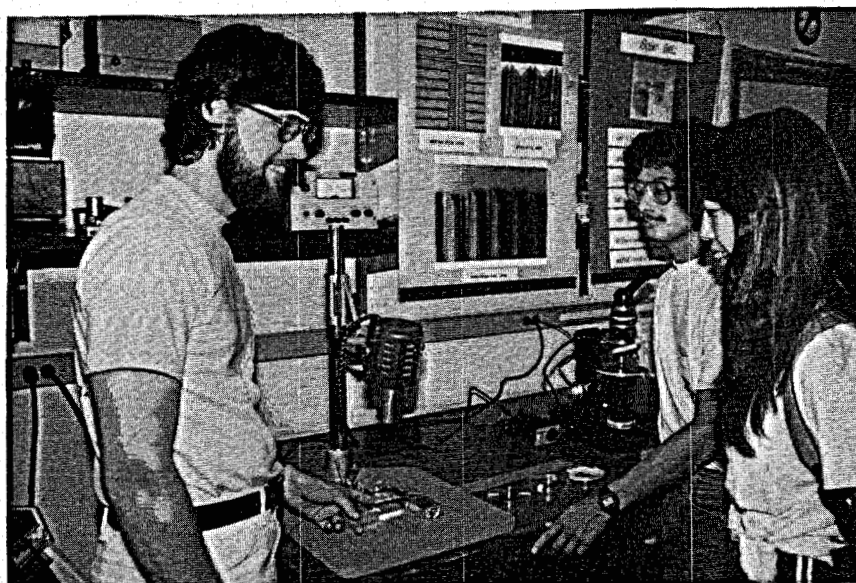
Concentrator Photovoltaic Cell Development

Early work was done in 1977 by Cheng-Chung Tseng on "corrugating" the surface of photovoltaic cells, which reduced the reflective losses of surface solar radiation and improved efficiency. James Holm-Kennedy further developed this idea, and invented a novel concentrator silicon solar cell. His work, combining both theory and experiment, includes numerical analysis of the cells and cell fabrication. The work is being carried on in the solid-state Physical Electronics Laboratory in the UHM College of Engineering and has produced working prototypes for evaluation.

A primary goal of this project is the final development of the Ridged Grid Solar Cell (RGSC), a photovoltaic device which features a unique ridged front surface geometry that enhances solar absorption and reduces series resistance and grid shadowing losses. The technology required to fabricate this device has been developed in the laboratory, and the testing phases of the project are essentially complete, with only minor refinements anticipated. A thorough theoretical treatment of this device showed that it should be able to handle currents associated with concentrations greater than 1,000 suns.



James Holm-Kennedy conducting a tour of his solid-state Physical Electronics Laboratory for Carl Takamura and Judy Rubano.



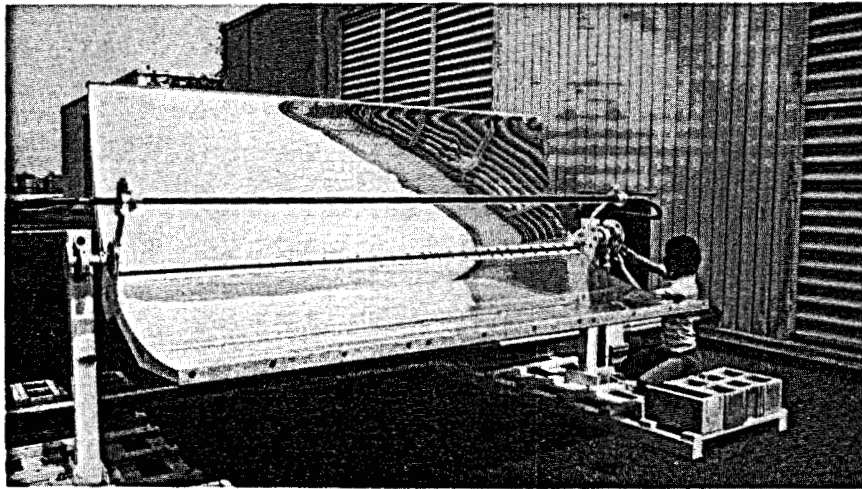
Students in the Physical Electronics Laboratory inspecting novel concentrator silicon solar cell invented by James Holm-Kennedy.

Educational Activities and Technology Transfer

In 1977 George Koide and Patrick Takahashi produced for the National Science Foundation a solar/wind applications study published by HNEI. In 1979 the *Solar/Wind Handbook for Hawaii* was written by Waqidi Falicoff, Koide, and Takahashi, for the USDOE.

The USDOE five-year grant (1978-83) for Solar Energy Meteorological Research and Training Sites funded a training curriculum that included an extensive list of courses relevant to solar energy, meteorology and engineering. Laboratory work was incorporated at solar radiation and wind field sites and relationships between solar input and energy output were emphasized.

The USDOE program was a precursor to the HNEI-funded Solar Energy Laboratory, designed and installed in 1982 by Michael Antal and his staff, on the rooftop of the UHM engineering building. This facility was established to keep the teaching curriculum in step with advancements in research activities and to allow researchers to share their expertise with graduate and undergraduate students in a laboratory setting. Experiments are designed to teach fundamental principles of thermodynamics and heat transfer and to demonstrate a variety of the latest solar technologies, such as flat-plate and parabolic trough collectors, solar cooling devices, and the salt-gradient pond. The laboratory provides basic facilities and equipment, such as monitors and data recorders, and is set up so that students may undertake their own independent research projects.

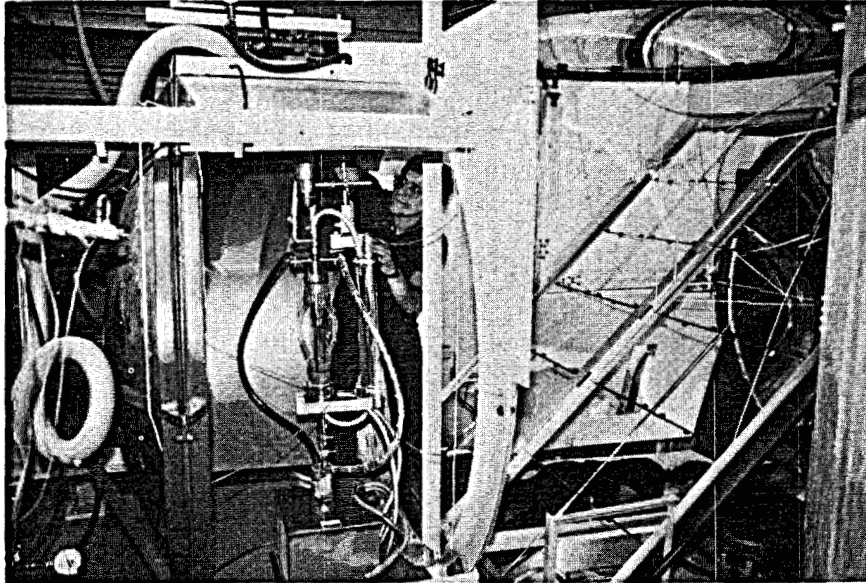


William Mok adjusts parabolic concentrating collector installed at the Solar Energy Laboratory on the roof of UHM Holmes Hall.

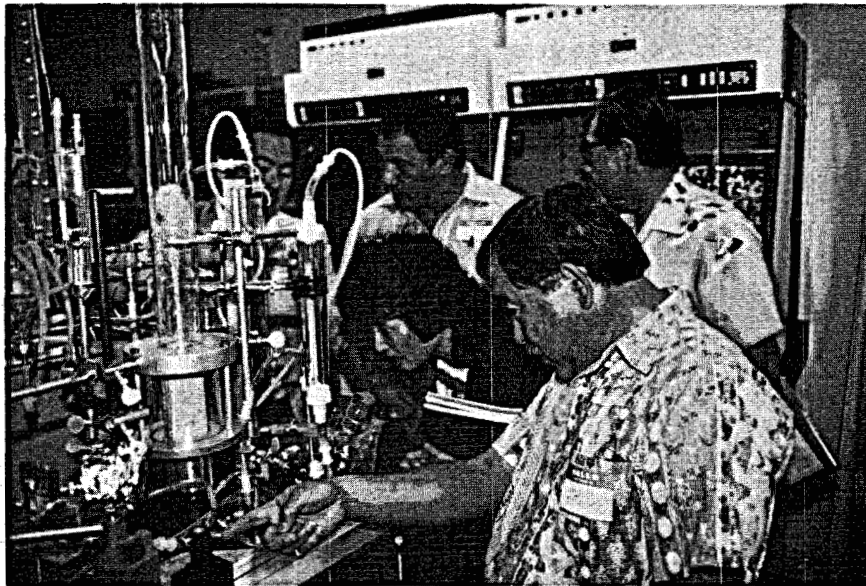


Touring the rooftop Solar Energy Laboratory are (left to right) Senators Henderson and Yamasaki, HNEI's Patrick Takahashi, and Senator Aki.

Other educational and technology transfer activities include workshops on topics such as solar hot-water systems and building designs for passive solar cooling and heating. A seminar series was held in 1983 on state-of-the-art photovoltaics and their applications in Hawaii, coinciding with DPED's publication of the *Guidebook on Photovoltaic Applications in Hawaii*, and a workshop on utility-scale PV systems was held in 1984. Numerous tours of wind machines and the residential PV sites, along with lectures and slide shows, have been conducted by HNEI for government officials, engineers, and school groups.



Ali Tabatabaie-Raissi with bench-scale model of sprouted-fluidized bed reactor installed in the Renewable Resources Research Laboratory.



Learning the fine points of the fluidized bed reactor in the Renewable Resources Research Laboratory are (clockwise from upper left) Reps. Apo, Takamine, Kiyabu, and Hashimoto.

Other Projects

Solar heat has been used effectively for crop drying, processing, dehydration, and preservation. Although dating to ancient times, solar crop drying must still be researched to improve large-scale, sanitary, controllable, and efficient solar methods. James Moy conducted investigations of solar crop drying in 1976-77 under HNEI, USDOE, and State Department of Agriculture funding. He found that the quality of solar-dried taro slices was comparable to that of air-drying and freeze-drying and a combination of direct radiant-drying and air-drying worked best for papayas, whereas banana slices browned easily when solar-dried.

Passive lighting and cooling are architectural applications of solar radiation. Buildings may be designed to make maximum use of shade for passive cooling and sunlight for passive lighting. Waqidi Falicoff of the UHM Architecture Department developed a simple method of analyzing the thermal performance of a building, primarily to determine the passive solar heating and cooling potential.

THE FUTURE OF SOLAR ENERGY CONVERSION IN HAWAII

Solar water heating has become a common and generally economical feature of new homes. Future growth depends partly on legislation of continued federal and state tax credits to ensure economic viability.

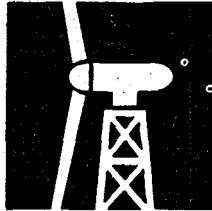
Residential PVs will continue to show minimal acceptability where utility power is available. Even if PV module prices drop further, the cost of an installed system will remain relatively high—the economics are not yet favorable. However, stand-alone systems will increase in number, especially for uses such as radio links, beacons, and agriculture. The trend clearly will be away from demonstration projects toward economically attractive commercial applications. HNEI will assist in the development of utility-scale systems.

A possible PV-thermal program for Hawaii is a project involving application of the HNEI-supported concentrator PV cell, which offers better conversion efficiency at high temperatures and, therefore, is a candidate for tracking concentrator systems. No future use is presently seen for trough reflector systems such as the one on Kauai, but Fresnel lens concentrators have evolved well and hold promise. Tracking flat-plate systems are also more cost-effective in Hawaii, where cloud reflectance can increase total insolation received.

Solar thermal point-focus (dish) systems show some promise. Though presently very expensive, they are in an advanced stage of development. The USDOE demonstration project on Molokai should help to evaluate whether such systems are functionally and economically feasible.

Solar ponds are expected to be demonstrated to provide very hot water for special applications. The use of these ponds for OTEC enhancement could also be attempted.

The wide variety of solar technologies planned for implementation offer both a challenge and an opportunity for Hawaii to continue its leadership position. Comparative studies and innovative experiments will continue to be supported by HNEI, but full-scale commercialization of the more exotic solar alternatives seem far on the horizon.



WIND ENERGY RESEARCH

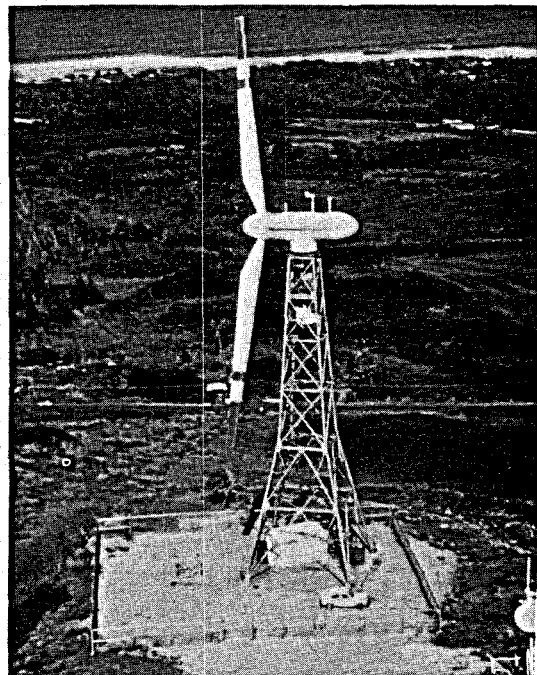
TEN-YEAR HISTORY

INTRODUCTION

Wind energy has been harnessed since the beginning of human civilization. Winds filling the sails of double canoes propelled the ancient Polynesians in their voyages to Hawaii. The Bishop Museum has lithographs of windmills in Honolulu as early as the 1830s. The traditional wind-powered mechanical water pumper "won the American West" by providing water for agriculture and ranching across the countryside. Small wind machines have been generating electricity for nearly 100 years and were widely used in remote areas until the 1930s when rural electrification brought relatively inexpensive and reliable electricity to most of the country. Individual water-pumping machines in Hawaii have been in operation for decades—one electrical system on Maui is forty-nine years old.

Wind energy conversion systems (WECS) use the kinetic energy of the wind to turn aerodynamically shaped blades connected to a shaft. The shaft can mechanically power a water pump or rotate magnets in a generator or alternator to produce electrical energy. The modern WECS era began only ten years ago, with development accelerated by the oil crisis. In California, a wind rush, perhaps even greater than the 1849 Gold Rush, has seen nearly 10,000 WECS installed through the end of 1984. Federal and California tax incentives have made wind farms a very attractive business investment and wind energy technology has benefited from the California experience, as many of the major problems associated with these developmental machines have been solved or are being tested. WECS from 200 to 400 kW are speculated to be in the most promising size range.

The most successful large-scale demonstration machine in Hawaii to date was the USDOE 200-kW MOD-0A, installed at Kahuku and operated by Hawaiian Electric Company (HECO). This WECS achieved a capacity factor of about 50 percent for an entire year's operation before it was removed at the end of the federal program. Hawaiian Electric Industries is installing in 1985 fifteen Westinghouse 600-kW machines that are similar to the MOD-0A. The next generation MOD-5B (3,200 kW) machine is scheduled to be installed at Kahuku in 1986.



USDOE 200-kW MOD-0A, installed at Kahuku and operated by Hawaiian Electric Company, was the state's first successful large-scale demonstration machine.

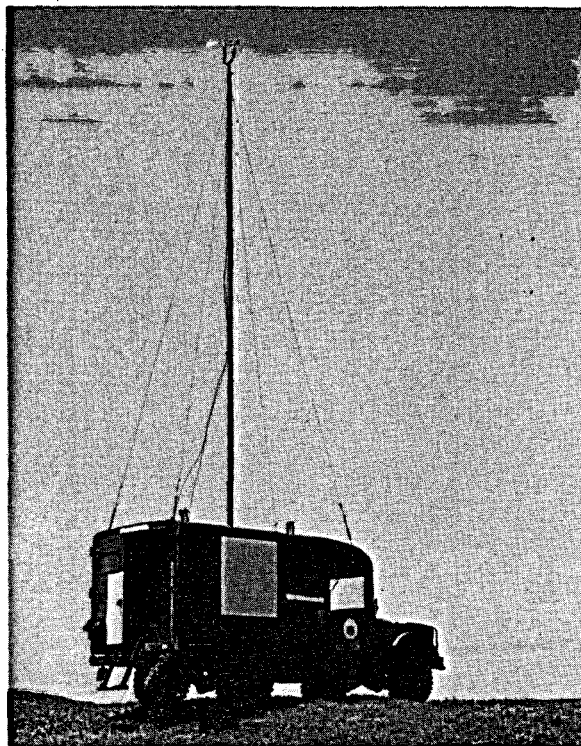
WIND PROGRAMS IN HAWAII

Early leadership for wind measurements was provided by Colin Ramage, and for the technology by Patrick Takahashi. Since 1978, D. Richard Neill has served as the HNEI Wind Energy Program Manager.

Several forecasts have been made of wind energy use in the state. In 1975 the Governor's Committee on Alternate Energy Sources for Hawaii indicated that wind energy had a significant potential to produce 10 percent or more of the state's electricity by the year 2000. The 1977 Hawaii State Senate's *Comprehensive Energy Program for Hawaii* estimated that there would be 150 megawatts of wind power on-line by 2000. In 1979 the *Legislative Energy RD&D Workshop Handbook* suggested that 30 percent of Hawaii's electrical energy by the year 2000 could be provided by wind energy, emphasizing that one megawatt-hour of energy storage must be provided for each megawatt of installed wind power. The *Hawaii Integrated Energy Assessment*, a report published by DPED and the Lawrence Berkeley Laboratory in 1981, estimated that a maximum of 20 percent of installed generating capacity for each county and 432 MW for Oahu would be on-line by 2005.

If wind energy potential alone were taken into account, the state's electrical requirement would be supplied many times over by wind systems. Winds in Hawaii are particularly consistent, with the prevailing northeast trades blowing 70 percent of the year at an average of 10 to 15 mph over the surrounding ocean, and enhanced over land by mountain ranges. A number of sites have been identified where sustained annual wind speeds average 16 to 23 mph, conditions that are excellent for electricity generation. However, the utilities currently estimate that they can accept a wind penetration level of only 10 to 20 percent of their generating capacity because wind is intermittent, unpredictable, and uncontrollable.

The HNEI and state wind research effort, therefore, has three foci: (1) to provide continual monitoring of wind energy potential; (2) to increase Hawaii's utilization of wind energy by helping to solve problems that face the utilities and other users; and (3) to develop non-utility-dependent wind applications. One focus of the wind program, and a special priority when it began ten years ago, has been to assess the state of the technology and to establish an ongoing program to document wind characteristics of the entire state by analyzing existing measurements and accumulating new wind data. The City and County of Honolulu provided funds for the initial study in 1974. With financial support from the state, counties, National Science Foundation, and USDOE, the University of Hawaii has continued this research by mapping the wind resource state-wide. Through the collaborative effort of the UHM Department of Meteorology and HNEI, five islands—Hawaii, Maui, Molokai, Oahu, and Kauai—have been mapped, using both fixed and mobile stations.



A van, or mobile measurement station, used by the UHM Meteorology Department for wind data collection.

A second focus of the state program has been to address the utilities' concerns about the interface between wind energy and their electrical grids. Energy storage may offer one solution to increasing the level of wind energy accepted. HNEI has studied the possibility of battery storage with support from USDOE, Sandia National Laboratories, and the state. Another technique could be wind-forecasting, which would give the power plant dispatcher additional lead time to bring other systems on-line when wind energy is likely to decrease or cease or to prepare for wind start-up.

The third focus is research of non-utility-dependent applications of wind energy. HNEI in cooperation with the College of Tropical Agriculture and Human Resources, the East-West Center, and the Kettering Institute is exploring the possibility of using wind energy in the production of nitrogen and phosphorus fertilizers. An innovative system of wind-powered water pumping developed by Don Avery may have additional applications, such as desalinating water by reverse osmosis. An objective of the HNEI hydrogen program is to produce hydrogen fuel for transportation use, windpower becoming a generation source. Alternatively, wind energy might be used to charge electric vehicle batteries, especially at night during off-peak periods. Concerns about corrosion, environmental impacts, and safety have also been part of the R&D agenda.

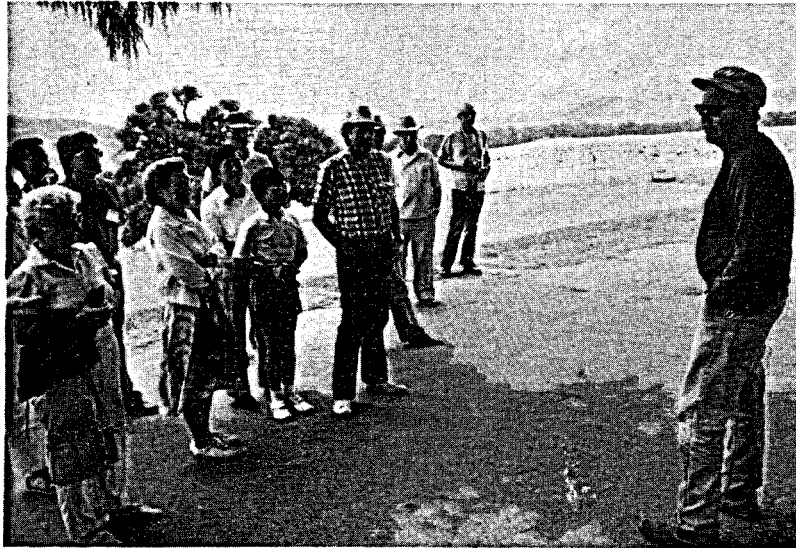
USDOE has participated in the state's wind energy program by providing three wind data stations for the local utilities and two small wind machines through the Rockwell International Rocky Flats/Small WECS Test Center. Although these developmental machines experienced problems, their output and the recorded wind regime were the best of 39 systems installed by USDOE/Rocky Flats under this program, and much useful experience was gained. USDOE, through NASA-Lewis, also provided the MOD-0A machine that operated successfully at Kahuku, and is funding the MOD-5B, scheduled to be installed at Kahuku in 1986 with the cooperation of Hawaiian Electric Industries (HEI).

PRIVATE-SECTOR WIND DEVELOPMENT

By the end of 1985, both the Big Island and Maui may exceed a 10-percent penetration level of wind energy into the utility grid, primarily from private-sector wind farm developers. There is concern that system instabilities could occur.



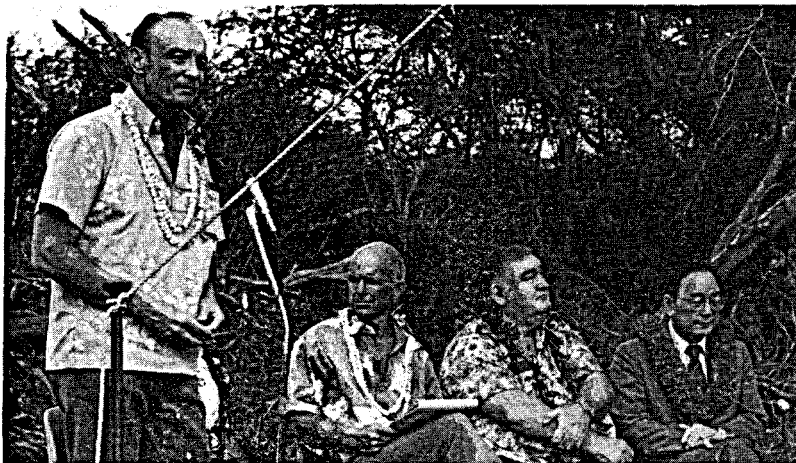
HNEI in 1977 suggested Kahua Ranch as an excellent wind power site — in operation today are 198 wind machines, the first large wind farm in Hawaii.



Kahua Ranch manager, Monty Richards, welcomes visitors to the wind farm.

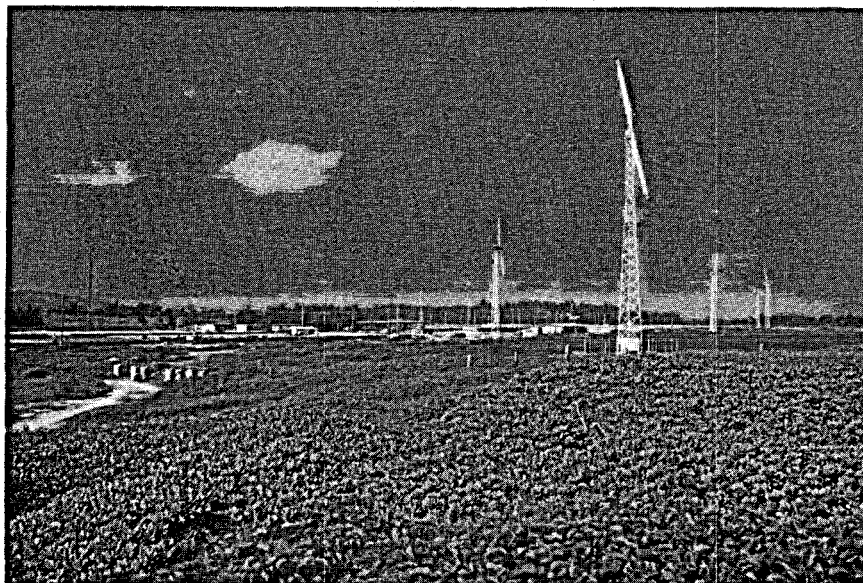
At Kahua Ranch on the Big Island a 3.4-MW wind farm of 198 Jacobs Wind Electric 17-kW WECS by Renewable Energy Ventures (REV) was dedicated in August 1984. Kahua Ranch also owns three 10-kW Jacobs WECS for its own electrical energy supply and hosts a small wind farm of six Carter Wind Systems 25 (25 kW peak output each). At South Point on the Big Island, Kamakani Ikaika Inc. has installed two WindMaster 200-kW WECS and, in 1985, plans to add 40 Carter Wind Systems 250's (at 250 kW each) for a maximum output of 10.4 MW. Approximately 40 other small WECS have been installed by individuals on the Big Island, and two additional wind farms with 150 17-kW Jacobs for 2.55 MW of power are planned by REV.

On Maui a 340-kW Danish WECS was dedicated in December 1984 at the Maui Electric Energy Park. About 20 WECS have been installed by individuals on Maui and four wind farms of about 5 MW each are actively being planned, with installation projected for 1985.



Speaking at the dedication ceremonies in December 1984 for Maui's largest wind turbine were (left to right) Arden Henderson, president of Maui Electric Company; Lafayette Young, developer; Mayor of Maui Hannibal Tavares; and U.S. Senator Spark Matsunaga.

Kahuku, Oahu, an 18-23 mph average wind regime, has long been a test bed for Hawaii wind machines. Currently in operation are 12 ESI-54's (50 kW being upgraded to 68 kW), four 250-kW Carter Wind Systems, a Jacobs 10-kW, and two wind-powered mechanical water pumps. Several developers have been seeking to install wind farms at Kahuku with intermediate-size (100-600 kW) machines. While plans for an 80-MW wind farm using megawatt-size WECS proposed for Kahuku by Wind Farms Ltd. in 1979 were tabled in 1981, HEI has announced a 9-MW Westinghouse wind farm. The USDOE MOD-5B, designed by Boeing, is a 3.2-MW machine with a 325-foot diameter blade that will be installed at Kahuku in 1986. The latter project will be jointly supported by USDOE and HEI.



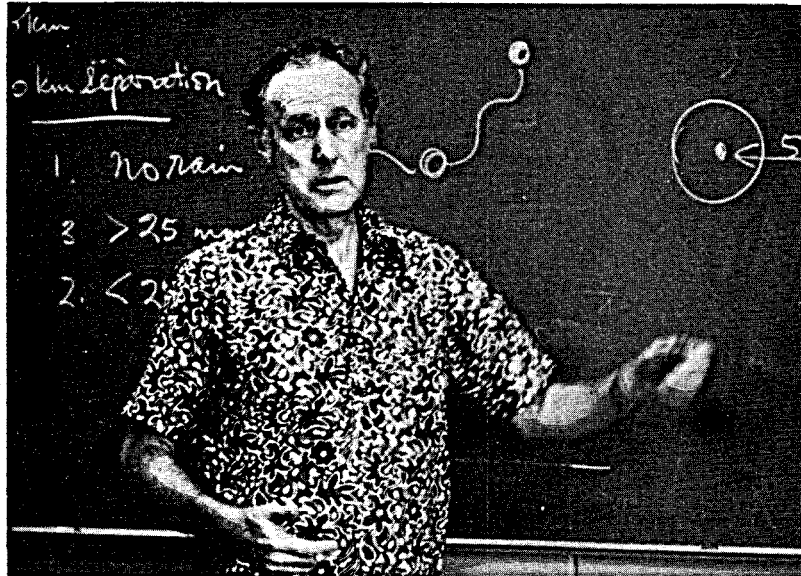
Wind machines at Kahuku visited during the July 1983 workshop included 12 ESIs.

HNEI WIND ENERGY PROJECTS

In the past ten years, HNEI has funded 18 wind energy projects at a total cost of \$917,706, of which \$658,422 were from state funds and \$259,284 from federal sources. This amount does not include almost \$1 million granted to the university by USDOE for its five-year Solar Energy Meteorological Research and Training Sites program, which had an important wind data element. HNEI project funds, supplemented by monies and assistance from a number of public and private groups, have focused on resource assessment, WECS reliability verification, wind energy applications, and nontechnological issues.

Wind Resource Assessment

The most important element of any wind energy development program is resource assessment. Accordingly, the basic element of HNEI's wind energy program has been a comprehensive wind resource assessment program. Key investigators in this effort have been Colin Ramage, Anders Daniels, and Thomas Schroeder. Three types of data are needed: information identifying general areas where wind speeds are high; long-term measurements in those areas identified as good wind regimes; and site-specific wind data to help determine precise WECS locations. Several years ago the UHM Department of Meteorology completed a state-wide assessment which established classes of windpower for each island. Several long-term data stations atop 150-foot towers were installed by UHM-Meteorology in 1977-78 to supplement wind data from airport stations already operated by the National Weather Service. Additional stations were erected by the USDOE Pacific Northwest



Colin Ramage, together with other researchers at the Department of Meteorology, conducted the early studies that became the basis for the state's wind resource assessment, a key element of HNEI's wind energy program.

Laboratory and HNEI after 1981. These tower-mounted wind measurement devices are located at the best wind sites on all five major islands and produce data that are collected and processed by HNEI as part of a state-wide network of base reference stations. UHM-Meteorology and HNEI also acquired mobile meteorological vans with sensing and recording equipment, hand-held TALA (tethered aerodynamically lifting anemometer) kites, and 20 portable wind data accumulators for short-term, site-specific data collection.

Public Information and Technology Transfer

Dissemination of these data and other wind energy information is a second important step in the process of wind energy development. Potential users must be aware of the available machines, the possible uses of wind energy, calculation of WECS economics, permitting processes, and other decision-making procedures. The HNEI *Wind Energy Technical Bulletin* is published and distributed periodically to make wind data available to all interested persons. The bulletin contains daily average wind speeds from the 11 base reference stations plus any short-term data collected and submitted by individuals. A wind energy map of one of the main islands identifying windpower classes, meteorological towers, and installed WECS is also included, along with brief news items, announcements, and reviews of publications relating to wind development in Hawaii. A 1983 publication, *Guidebook on Wind Energy Conversion Applications in Hawaii*, addresses many of the major issues affecting the introduction of windpower, including a summary of wind resources throughout Hawaii; potential applications of WECS; decision points for installing a WECS; environmental, social, and safety issues; the economics of wind energy; and a list of references.

HNEI maintains an up-to-date information file on available wind machines, a library of wind energy materials, and an instrument loan program for wind data collection. Staff members have responded to requests for data and/or advice from wind farm developers and potential WECS owners, many of whom subsequently decided to install machines.



D. Richard Neill demonstrates the hand-held anemometer, a device to measure wind speed, to participants of the wind workshop field practicum at Kahuku.

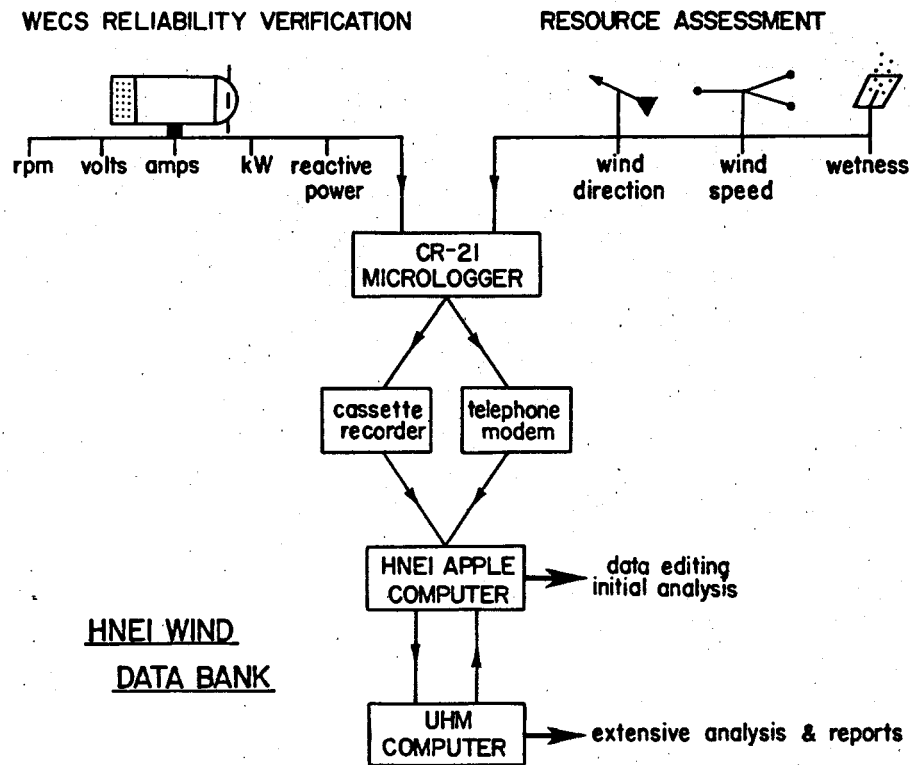
HNEI also assists the public by disseminating information and promoting technology transfer through its annual wind energy technical workshop. The first workshop in 1978 drew broad-based attention to the potential of windpower in Hawaii. An annual event since 1980, the workshops now last up to six days and include presentations and discussion sessions on both the technical issues of WECS reliability and siting, and issues of safety, zoning and land use, financing, and environmental and social impacts. Field trips to wind development sites on Oahu and at least one of the Neighbor Islands are regular features of the workshops.

WECS Reliability Verification Program

As most of the small WECS available today are still essentially developmental, each installation in Hawaii, in effect, is a learning machine. It is necessary to have long-term operating experience, supplemented with adequate instrumentation and performance data, in order to verify WECS reliability so that the economics of the systems and the level of investor risk can be determined. HNEI's Reliability Verification Program was established to encourage and provide for such testing.

The monitoring program utilizes Campbell Scientific CR-21 microloggers to record the WECS kilowatt output, amps, volts, RPM, and attendant wind speed. The CR-21 system documents performance by recording data at six-minute intervals on cassette tapes which are evaluated by an Apple computer for printing, follow-up analysis, and storage. Data on performance are collected for at least a year, during which time a detailed log is kept of all problems encountered in installing, operating, and maintaining the WECS, and of how the problems were solved.

In verifying the performance of WECS, projects have been carried out to test the effects of Hawaii's damp, salt-laden air on various components. Anders Daniels conducted a vertical corrosion profile study of Kahuku by using the string of a TALA kite to measure corrosion at various elevations above the ground. Jorn Larsen-Basse has been studying corrosion on various types of engineering materials from both natural exposure and laboratory testing at the Natural Energy Laboratory of Hawaii. HNEI has provided field support for weather testing of a section of the MOD-5A wooden blade at Kahuku, in cooperation with GE, HECO, and the Gougeon Brothers blade manufacturers.

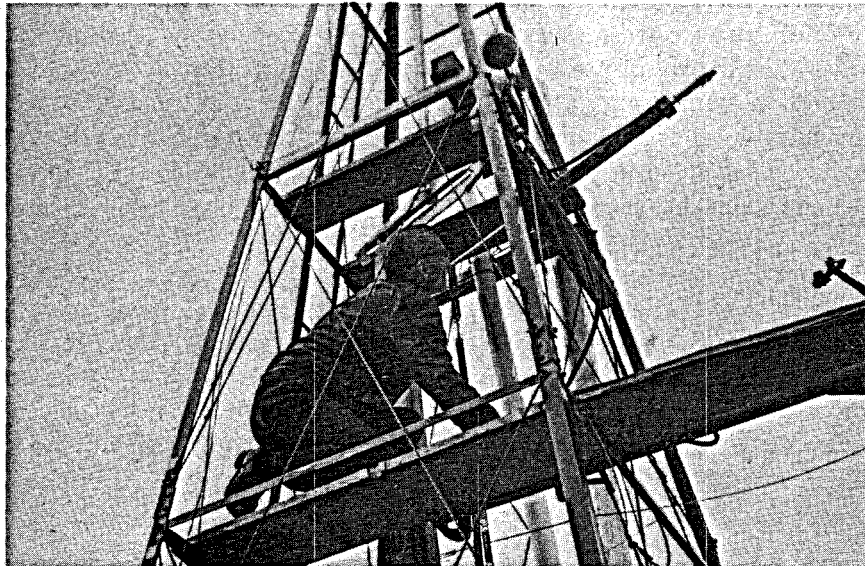


Schematic of HNEI's WECS monitoring system.

Wind Energy Applications Program

The Wind Energy Applications RD&D Program addresses such issues as installation procedures, storage, corrosion, output optimization, and interfacing with applications. The test center for this program was originally located in Kahuku, where HNEI had installed a 15-kW Wind Tech and a 1.8-kW Enertech, and had purchased a 15-kW Millville-Hawaii for installation. However, the Wind Energy Application Research Center has since been relocated to Maui.

HNEI has supported several wind-water pumping projects, the oldest and most widespread mechanical application of wind energy. Don Avery developed a number of improvements in mechanical pumping under three USDOE Appropriate Technology Research grants and HNEI funding. His automatic stroke control device allows the flow rate to increase with the cube of the wind speed (rather than just doubling when wind speed doubles, as in conventional wind pumps). The output is greatly increased in higher winds, and pumping also starts up in lower winds than was possible with earlier systems. Applications being considered for Avery's device are desalinating water by reverse osmosis and pumped-storage hydroelectricity.



Don Avery climbs his wind powered water pump to make some adjustments in its operation.

Aquaculture has a considerable potential for development in Hawaii, but requires a great deal of energy for water circulation, aeration, heating, and filtration. K. Gopalakrishnan was funded by HNEI from 1981 to 1983 to investigate the feasibility of meeting these energy needs with wind and solar energy, while using caprock water to conserve the municipal water supply and to eliminate the use of brackish water from a nearby canal. HNEI has funded other studies for novel uses of wind energy, including wind-powered wastewater treatment; wind-powered irrigation pumping for land reclamation; and development of sail-assisted technology for Pacific marine transportation to augment ship propulsion and reduce diesel fuel consumption.

Another aspect of HNEI's wind energy application RD&D program has been to initiate research on utility interface and storage. Supported by HNEI and the NASA-Lewis Research Center, H. H. Hwang completed a study in 1977 on the connection of WECS to electrical grids. The study showed that given a WECS with variable power output and a utility grid with variable load but no system instability, synchronization can be accomplished by using an automatic synchronizer at the connection site. When the current, frequency, and sequence of the generator and the utility grid are identical, connection is achieved automatically. Tower shadow and wind gusts could cause fluctuations in the wind generator output, but these problems are not insurmountable.

Wind Energy Battery Storage

The Wind Energy Battery Storage (WEBS) project began in 1981 under funding by USDOE/Sandia National Laboratories and the state, and was conducted by HNEI staffers George Curtis, Byron Auker, and D. Richard Neill. WEBS was conceived as an R&D effort to provide energy storage to meet utility needs and ultimately to enable utilities to accept a much greater level of wind-generated electricity. The purpose of the project is to analyze, design, construct, and test a battery storage system involving interaction between batteries, WECS, and a utility system. The WEBS system is designed to store intermittently produced energy from wind and to distribute the power as needed to meet long- or short-term utility demands.

A recent project for HNEI by Thomas Schroeder would increase the contribution of wind power to a utility grid using a wind-forecasting system. Forecasting changes in wind speed and the resultant wind power output would notify a utility dispatcher in advance to increase or decrease the amount of energy on-line from back-up generators. It is possible that the level of wind energy a utility uses can be increased significantly without sacrificing the stability of the system through a combination of a forecasting "early warning system," a utility's load shedding and rapid recovery capability, and battery storage for excess energy produced.

Nontechnological Issues

Wind energy developments must prove to be not only technologically feasible, but economically, environmentally, and sociologically sound as well. HNEI has studied economic, as well as environmental and social issues: safety for people and wildlife; noise and visual impacts; TV/radio interference; legal questions of infringement and wind rights; zoning and permitting; along with profitability, tax incentives, fair payment from utilities for electricity produced, and financing options.

THE FUTURE OF WIND ENERGY CONVERSION IN HAWAII

A study by HNEI indicated that Hawaii's wind energy resource potential greatly exceeds utility demand; however, the utilities believe that they can only accept 10 to 20 percent of their demand from all intermittent sources. Hence, an important element of HNEI's wind program has been directed toward resolving wind energy-utility interface problems.

Developing non-utility-dependent applications is a second means of increasing the utilization of wind energy. The HNEI program plans to research, develop, test, and evaluate such wind energy applications as advanced wind-powered water pumping, desalination by reverse osmosis, nitrogen/phosphorus fertilizer production for agriculture and aquaculture, hydrogen production, and electric vehicle battery charging. Maui County and Maui Electric have shown a strong interest in working with HNEI in these efforts. Much of this research could occur at the proposed Maui Renewable Resources Research Facility.

The goal of attaining and exceeding 10 percent of Hawaii's electricity requirements from wind energy certainly is achievable. There has been much progress during the past decade and more can be expected.



OTHER RENEWABLE ENERGY RESEARCH

TEN-YEAR HISTORY

INTRODUCTION

When HNEI was created in 1974, five major renewable energy research areas were delineated for study: biomass, geothermal, OTEC, direct solar, and wind. Most HNEI research projects fall within one of these categories. However, through the years, HNEI has also funded or participated in projects associated with more than one developing energy technology and subsidiary programs. Support has been provided for assessments of the technological feasibility and the social, economic, and environmental impacts common to renewable energy resources. In the policy-making arena, HNEI has undertaken an effort to provide planning tools for those determining Hawaii's energy future through legislative workshops, county energy self-sufficiency plans, national conferences, lectures, and symposia.

Often project ideas originate with HNEI. At other times, proposals are submitted in response to outside requests for proposals, and the work is completed by the HNEI staff and university personnel. By maintaining current information on USDOE's requests for proposals, program opportunity notices, and other announcements, HNEI is able to provide information on grant opportunities to the public and private sectors alike.

An informed and concerned public is vital to the progress of natural energy projects, and HNEI provides this informational service. In addition to technical reports, HNEI publishes and distributes materials written for the lay person. Newsletters, brochures, and reports are disseminated to a cross-section of citizens from a wide range of professions and backgrounds. Talks and/or exhibits are given to interested groups and a library of natural energy publications is maintained by HNEI.



HNEI poster display at the Pacific Congress on Marine Technology conference held in April 1984.

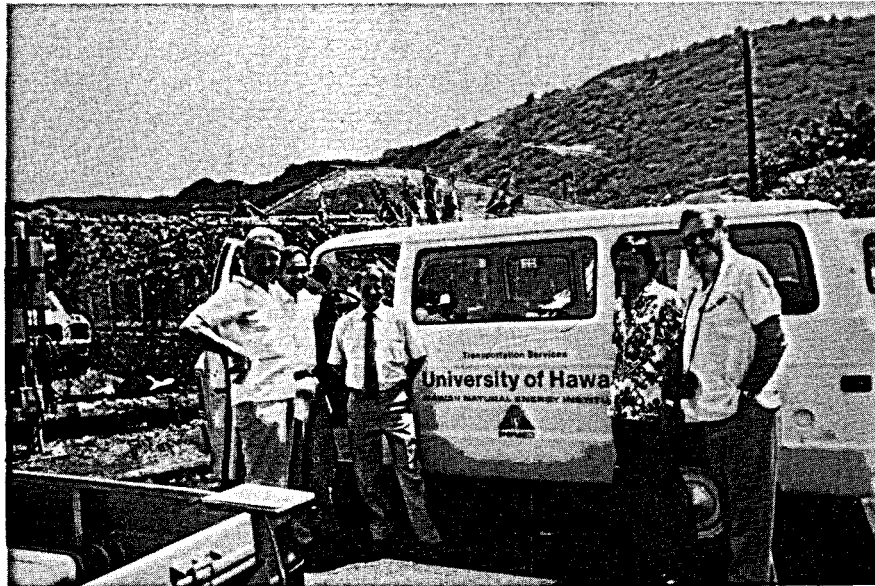
Education is an important function of HNEI. Researchers on the various projects learn much through their studies, and are willing to share that knowledge through colloquia and reports. In order to promote first-hand experience with natural energy technologies, graduate students are included in HNEI endeavors whenever possible, and work closely with the faculty. At present, HNEI is directly funding the research programs of three graduate students in different areas of renewable energy and is planning to recruit additional graduate students in a program to begin in fall 1985.

DEVELOPING RESEARCH PROJECTS

Research projects in the "Other" category address technological issues from the durability of hardware components against corrosion and biofouling to environmental baselines and impacts investigations. Nontechnological issues are related to studies of economic feasibility, social impacts, and institutional structures. New program areas sometimes evolve from projects in this category. For example, the Hawaii Hydrogen Program began with two projects funded in 1982-83, while a new program area is being defined in "transportation alternatives," covering research on electric vehicles, biomass transportation fuels, and hydrogen fuel.

ELECTRIC VEHICLES

The use of electric vehicles (EVs), which potentially could be charged by electricity produced from Hawaii's renewable energy resources, may some day reduce Hawaii's dependence on imported fuels. Hawaii was chosen as one of the original sites for the USDOE State and Local Government Electric Vehicle Demonstration Program because of our favorable climate, routes over relatively flat terrain, low speeds, and short driving distances, as well as the high level of state, private, and university support for renewable energy projects...and, it is one of the very few sites that has continued to be supported.



At the EV workshop (left to right): C. J. Smits, EV program Manager (DOE-Nevada); Warren Harhay, EV expert; Ken Friedman, Director of the EV Test and Evaluation Program (DOE-Washington, DC); Frank Matsumoto, Director of UH Transportation Services; and HNEI's D. Richard Neill with the UH/HNEI Jett van.



EV program manager D. Richard Neill demonstrating the electric vehicle to elementary school children.

Fifteen internal-combustion-engine vehicles were converted into EVs, and were operated and maintained by UHM Transportation Services, with H. H. Hwang originally as the principal investigator and Dick Neill as the program manager. More than 50 drivers were trained and the vehicles were assigned to various units of the university and to DPED. The four-year program began in 1980 and has been a mixed success. Although the EVs have been plagued with numerous electronic and mechanical problems, the process of correcting the initial defects and day-to-day problems have taught program participants much about how EVs should be designed, maintained, and operated. Most of the problems involving batteries and controllers are being solved with new batteries designed especially for EVs and the new solid-state transistorized controllers now available.

Recognizing that its broad program had been premature for the state of EV technology at the time, USDOE is presently concentrating on the development of improved systems and test-and-evaluation, rather than demonstration, and is limiting its program to a few sites. Basic research is needed to provide new technology for possible hybrid vehicles and other improved EV system elements.

HYDROGEN FUELS

Hydrogen may be the perfect fuel: it burns cleanly, has high energy content per pound, is lightweight and condensable to about 1/700 of its volume in liquid form, and, if a cost-effective means is found to split water, abundant. Petroleum-dependent Hawaii has numerous renewable energy sources from which hydrogen can be produced and would stand to gain much if a flexible hydrogen economy becomes a reality.

Preliminary hydrogen research activities were initiated with USDOE funds supporting Bruce Liebert in 1981 and Shiv Sharma in 1982. Liebert has been working since then on the electrochemistry of hydrogen storage in transition metal hydrides. Sharma is conducting a systematic investigation of the interaction of gaseous hydrogen with transition metals and their alloys under conditions of high pressure and high temperature.

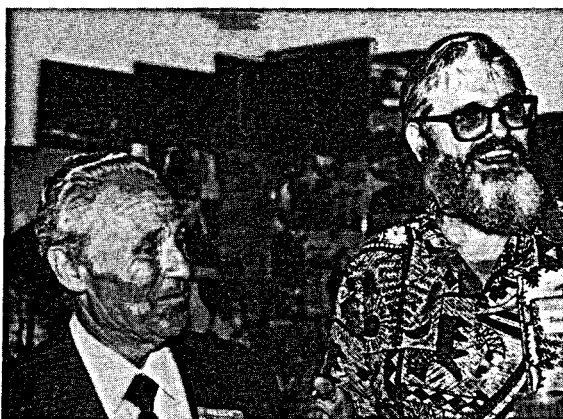
In January 1983 HNEI organized a Hawaii Hydrogen Program group which includes university researchers, community representatives, and officials from government who meet to coordinate hydrogen research efforts in the state. Melvin Bowman, formerly of the Los Alamos National Laboratory, is an advisor to the program. Cooperative efforts are being worked out with the Florida Solar Energy Center, Brookhaven National Laboratory, Oak Ridge National Laboratory, and the Solar Energy Research Institute.

The Hawaii State Legislature in April 1983 appropriated \$50,000 for R&D of hydrogen fuel. HNEI distributed the funds as seed grants or as supplements to USDOE grants for hydrogen projects at the University of Hawaii. Five projects were funded in 1983-84 in addition to those of Liebert and Sharma.

In May 1984, HNEI, DPED, the East-West Center Resource Systems Institute, and the Pacific International Center for High Technology Research (PICHTR) sponsored the first Hawaii International Symposium on Hydrogen Produced from Renewable Energy. An international roster of speakers informed attendees about the present state of renewable hydrogen research and identified directions for future research. As a follow-up to the symposium, HNEI and the Florida Solar Energy Center jointly proposed to USDOE a major international hydrogen research and applications program.



More than eighty representatives of government, academia, and the private sector heard hydrogen researchers discuss the latest findings at Hawaii's Hydrogen Symposium.



Melvin Bowman (left), advisor to the Hawaii Hydrogen Program, confers with D. Richard Neill, symposium coordinator.



John Bockris and Alessio Mezzina debate the issue of how long it will take to see the "hydrogen economy" emerge.

A condensed version was included in the package of proposals sent to the Japanese government as possible projects for PICHTR. Proposed projects include simultaneous electric power and hydrogen production using concentrated sunlight on photovoltaic cells; algal systems for hydrogen production; solar-fired chemical reactor conversion of biomass into hydrogen; use of wind, hydro, geothermal, and ocean thermal energy for electrolysis of water; and experiments with hydrogen for vehicular and fuel cell applications.

SUBMARINE ELECTRIC CABLE

Large-scale development of Hawaii's renewable energy resources depends on a market for the energy produced. With more than 80 percent of the state's electrical energy use on Oahu and most of the renewable energy resources on the other islands, energy self-sufficiency can only be achieved if there are systems for transporting energy among the islands. Linking the islands with a state-wide grid would offer the advantages of balancing supply and demand and allowing back-up assistance in case of major power outages on one or more islands.

An initial study by H. H. Hwang in 1975-76 suggested the possibility of connecting Maui, Molokai, and Lanai by undersea electric power cables. Technical feasibility was confirmed by cable manufacturers and installers, and economic and technical benefits, such as the deferral of capital costs needed for additional generation units, were reported by utilities. This study helped to pave the way for the Hawaii Deep Water Electrical Transmission Cable (HDWC) program, which began in 1981 and was funded by the state and federal governments and private industry. The prime contractor for design of the cable is Hawaiian Electric Company (HECO) with Parsons Hawaii, Pirelli Cable Corp., Hawaiian Dredging and Construction, the Hawaii Institute of Geophysics, and HNEI involved in various aspects of the work. The preliminary cable design has been completed, along with a DPED-funded study of the legal, institutional, and financial aspects which suggests that private, public, and hybrid entities might coordinate efforts to buy, install, and operate the cable.

Preliminary design of the cable system has been completed based on research of at-sea routes, cable design studies, and a look at cable-laying vessels. The technical problems of laying a cable almost 175 miles long and in depths down to 7,000 feet have been solved in theory. Now under way are environmental analyses, electrical grid system integration, and materials and corrosion studies. Jorn Larsen-Basse has been instrumental in defining the experimental program for the cable materials studies. His investigations include tests of the antifouling properties of a cupro-nickel cable wrap, long-term seawater corrosion of stainless steel and aluminum, and abrasive wear of stainless steels.

ENERGY STORAGE TECHNOLOGIES

Energy stored in the forms of liquid or gaseous fuels are other possible solutions to the problem of transporting energy produced from renewable resources to the locations where they will be used. Storage in the form of batteries or fuel cells can also help to solve the problem of intermittence, especially for wind and direct solar energy, and to make these energy supplies available at times of greatest demand.

Transportation fuels are a key factor in Hawaii's attainment of energy self-sufficiency, since more than 60 percent of the state's energy requirement is for ground and air transportation fuels. Hydrogen can be stored as a compressed gas or in metal hydrides for ground transportation use, or liquefied for ground and aviation fuels. Other possibilities for transportation fuel are ethanol, methanol, methane, liquid and gaseous fuels from pyrolysis, and oil from algae—all forms of stored

biomass energy. (See Biomass 10-year History.) HNEI is coordinating these efforts in fuels research through a new Transportation Alternatives Program. The first issue of the *Alternative Transportation Newsletter* was published jointly by HNEI and DPED.

Utilities have limited the proportion of their generating capability that comes from renewable sources because of the intermittence and unpredictability of wind and solar energy resources. HNEI's wind energy storage (WEBS) project (described in the Wind 10-year History) was started as a way of enabling utilities to maintain control of their generating capabilities and loads, while maximizing the contribution of wind energy. A computer model of a wind-powered generating system, originally developed as part of an energy self-sufficiency plan for Molokai, incorporates storage potential and can be applied to larger systems, as well as to solar and other renewable energy electrical generation schemes.

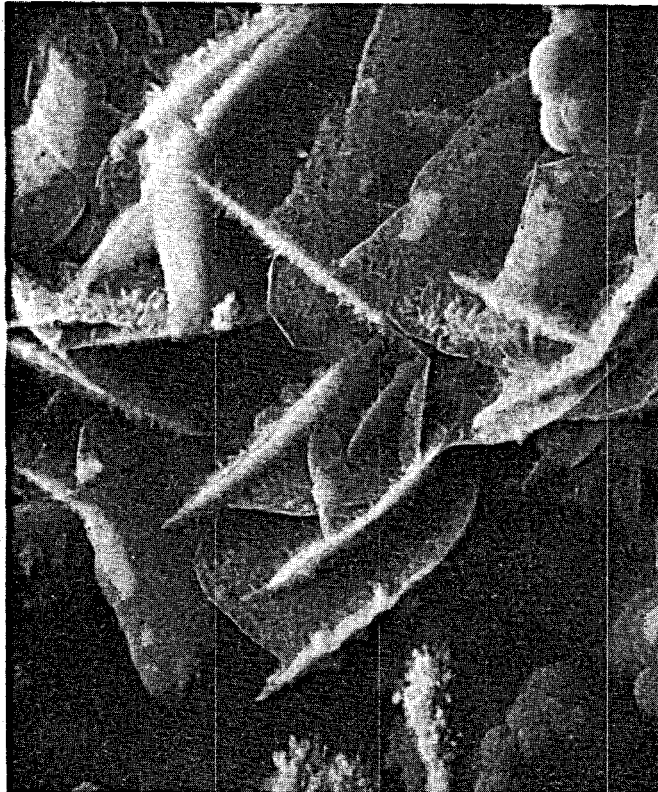
Utilities are also investigating fuel cells—hydrogen-powered batteries that turn chemical energy directly into electricity and heat. Fuel cells can either be grid-connected or stand-alone. Hawaii's gas utility, Pacific Resources Inc. (PRI), plans to install two 40-kW on-site fuel cells in residential and commercial buildings to provide both heat and electricity. Larger fuel cells can be used by utilities to assist in utility load leveling, that is, using stored energy to meet increased user demand without increasing generating capacity. Fuel cells may also provide the key to extending the range of electric vehicles.

Pumped-storage hydroelectricity is an energy storage method that was initially studied under a DPED grant in 1978 and considered again in 1980 as part of Molokai's energy self-sufficiency action plan, but was never built. In this process water circulates between two reservoirs through a network of pipes and tunnels. Water is allowed to flow from the upper or fore-bay reservoir to turn a turbine generator sited at a lower elevation. During off-peak times, water from the after-bay reservoir would be pumped back up to the fore-bay reservoir by a wind-powered water pump and stored until needed to operate the generator again. A 90-kW system was considered for Molokai, and larger systems have been proposed recently for the Kahua Ranch and South Point Wind Farms on the Big Island.

MATERIALS AND CORROSION STUDIES

Corrosion is a serious natural degradation process affecting most renewable energy systems, as well as other structures and machinery in Hawaii. Strong winds, a salt-laden marine atmosphere, and the tropical sun tend to corrode, crack, and wear down wind machines, solar collectors, and PV panels. Many renewable energy systems are limited by the materials used in their hardware. For example, geothermal brine needs to be transmitted in special piping materials and OTEC involves salt water and metallic heat exchangers. HNEI has funded corrosion studies in geothermal, marine-related, and atmospheric applications.

In a two-year study by Jorn Larsen-Basse, various materials were systematically exposed to conditions of corrosion in different locations and from different sources: brine from HGP-A and atmospheric corrosion in Manoa Valley and at Ke-ahole Point. These inland and coastal areas are representative of many solar and wind resource sites in the state. The overall objective of this project was to develop an understanding of the basic mechanisms that control corrosion affecting renewable energy projects in Hawaii. Larsen-Basse's studies are continuing with funding from Argonne National Laboratory and the American Society of Testing and Materials.



From corrosion studies conducted by Jorn Larsen-Basse, photograph shows scale and corrosion products formed on copper magnified 1850X.

ENVIRONMENTAL IMPACTS

The most visible and possibly irreversible effects of renewable energy resource development projects may be their impacts on the environment. Although they are more benign than fossil fuels or nuclear energy, and could have positive effects, large-scale operations of many renewable energy technologies have not been deployed, so that although some effects are known, others may be completely unpredictable. Moreover, island communities and environments are often more impact-sensitive than those on continents because of isolation and insulation. As a chain of islands, Hawaii is a wholly unique laboratory for energy/environment R&D, with special significance locally, nationally, and globally. In many respects, Hawaii is an ideal "pilot plant" for tests of emerging renewable energy technologies.

The best method of determining whether an environment or community has been impacted—and to what extent—is by taking baseline measurements and monitoring the environment during operation of the energy system. The concepts of preliminary baseline assessment and follow-up monitoring were pioneered at the Hawaii Geothermal Project (HGP-A), the first productive geothermal well in Hawaii. Even before final site selection, the first environmental baselines were being determined: field surveys had been launched and sampling programs initiated. By May 1975, sampling of air quality, soil chemistry, and plant tissue composition had all begun. In addition to field checks of the immediate drilling area, evidence of rare, threatened, and endangered plant species were sought within a one-kilometer radius as part of a study of ecological structures. At the same time, other study groups were examining the same area for evidence of artifacts with possible cultural or archaeological significance.

Out of such early explorations has emerged HNEI's present commitment to address impact issues and environmental quality concerns. Baseline environmental impact studies and continued monitoring have been performed for many renewable energy resource projects in Hawaii, from OTEC to biomass. The most prominent researchers in this area have been the husband and wife team of Sanford and Barbara Siegel. Sanford Siegel, HNEI Environmental Coordinator, was involved in baseline studies for HGP-A and has organized data collection for subsequent geothermal resource exploration and development phases. Mercury and hydrogen sulfide concentrations in the air at HGP-A have been measured for the past ten years and are continuing. The Siegels are also redetermining atmospheric mercury levels for 1972-79 at various locations on Maui. (See also Geothermal 10-year History.)



DPED Alternate Energy Branch Manager Tom O'Brien (left) and HNEI Environmental Coordinator Sanford Siegel discuss Rotorua H₂S study, with Jerry Comcowich, Professor of Education, and Takeshi Yoshihara, DPED Energy Program Administrator, in the background.

Other studies on the impacts of existing renewable energy projects on plant and human life are being performed. Recent and current studies include: the toxicity of mercury and hydrogen sulfide to plants; the effects of protective agents such as sulfur and vitamin B-1; the effects of brines on plants, including Ohia and papaya; the application of sulfur-metabolizing bacteria to hydrogen sulfide abatement; and the effects of OTEC chlorination on the ocean chemistry and biology. As the number of renewable energy projects in Hawaii increases, environmental conditions will continue to be studied and monitored because their cumulative impacts will be felt more strongly.

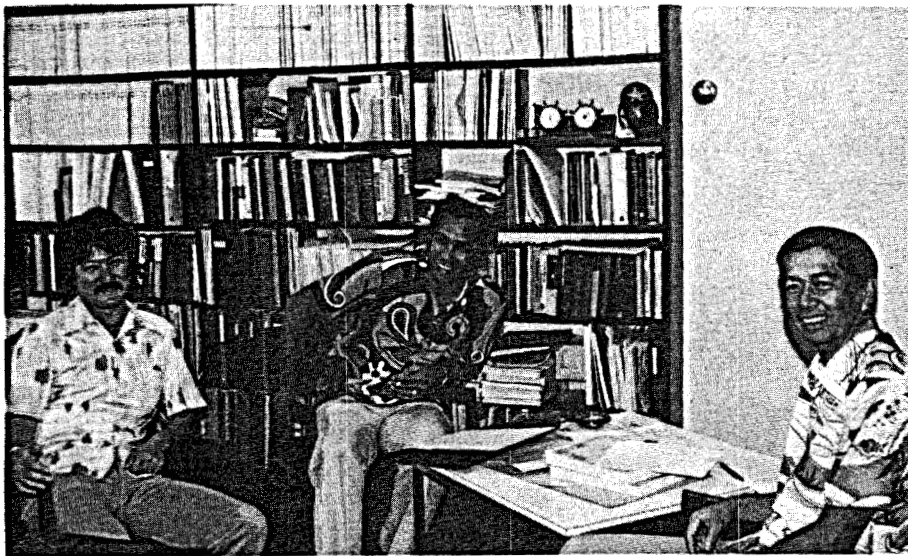
OTHER NONTECHNOLOGICAL ISSUES

The transition from conventional to innovative energy systems requires careful planning to protect Hawaii's people and environment while new energy benefits are gained. HNEI has commissioned various *ad hoc* task forces, including UHM representatives from the Environmental Center and the fields of sociology, anthropology, botany, law, and business. Methodologies have been developed by these groups for performing tasks needed to address a wide range of social, legal, and economic issues.

Social considerations, especially, mean involving local residents as fully as possible. It is important that questions and concerns be raised in public forums and explored further in programmed studies. Residents living near project areas will feel the impacts that follow natural energy development most directly and all citizens ultimately will pay for the costs of new energy sources.

Existing laws and statutes have been examined to determine whether they encourage or discourage natural energy development, and legal actions to accelerate desired advancements have been defined. The HNEI task forces have also established economic rationales for pricing alternative energy, and because capital costs are high for most of these developing natural energy systems, the task forces have explored means by which help could be provided by the state and federal governments at life-cycle advantage to Hawaii.

HNEI has conducted or assisted in engineering and economic feasibility studies, systems integrations, and energy demand analyses. One area in which HNEI has taken a leadership role is in energy self-sufficiency (ESS) planning for the counties. In the late 1970s each county, with HNEI assistance, worked out its own self-sufficiency plan, taking into account available resources, consumption levels, and needs. HNEI also funded projects that collected baseline socio-economic data for Molokai's ESS planning; studied the social, environmental, legal, and economic aspects of ESS and of renewable energy development in general; and assisted in the R&D for energy management plans for all islands. The HNEI Self-Sufficiency Coordinating Committee enables the counties to compare plans, share results, and discuss problems.



Ralph Masuda (left) of Maui County and Kelvin Kai from Kauai Electric Company (center) discuss their counties' energy self-sufficiency plans with then HNEI Director Paul Yuen.

Gordon Dugan and Patrick Takahashi initiated a two-year feasibility and assessment study in 1978 which integrated bioconversion activities in Hawaii, including growing and cultivating processes, recycling of wastes, and the production of fertilizer, feed, electricity, and liquid fuels. This system was refined and expanded six years later when the Pacific Basin Biofuel Workshop produced a bio-fuels action plan for Hawaii and the Pacific Basin.

A demand analysis of ground transportation fuels in Hawaii made by PingSun Leung beginning in 1981 has facilitated projections of future energy use. He developed, tested, and refined an econometric model to analyze past trends and to forecast demands for ground transportation fuels in Hawaii for the next 25 years. The economic implications of natural energy resource development were studied by Robert Kamins, Jack Suyderhoud, and Edwin Fujii. They found that existing state and federal laws have stimulated the development of natural energy, particularly the Public Utilities Regulatory Policy Act (PURPA), which requires the utilities to pay the full avoided costs for electricity produced from renewable resources. HNEI published their study, *Pricing New Energy Inputs into Electrical Supply in Hawaii: An Evaluation of Federal and State Pricing Policy for Electricity Generated from Alternative Energy*, in 1980.

THE FUTURE OF ENERGY R&D IN HAWAII

Research develops the base for the future. Hawaii is now on the threshold of commercializing ocean energy, geothermal energy and wind power because of the early work of researchers.

Research can also re-vitalize. The sugar industry is in trouble, and could someday move in the direction of energy and chemical plantations suggested in preliminary studies.

What holds for the future? Biofuels with methanol in the shorter (5 to 15 years) term and hydrogen past the turn of the century, loom as high priority R&D targets. Energy bridge options, such as the deep sea transmission cable, methanol, or hydrogen, need to be more closely investigated. Storage—metal-air batteries, undersea compressed air, flywheels—should gain higher priority.

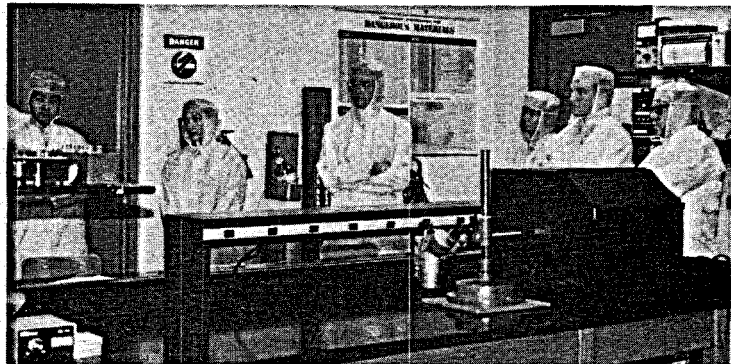
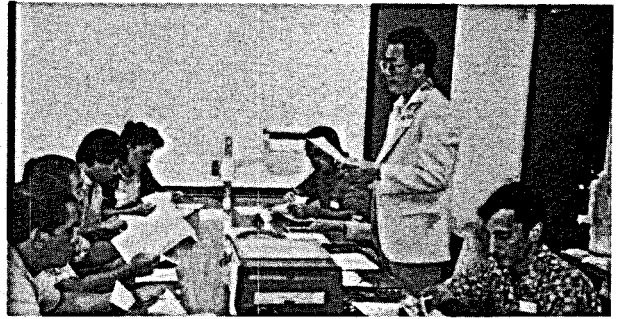
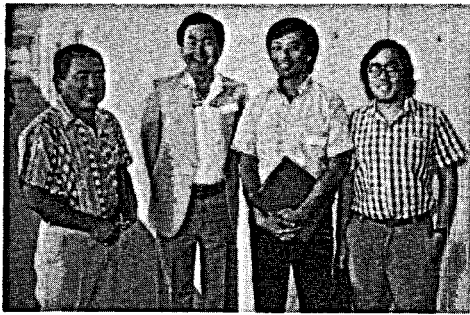
Finally, the transition from conventional to innovative indigenous energy systems will continue to require careful planning to protect Hawaii's people and environment. HNEI's activities in environmental assessments, community outreach, and legal, economic, and other nontechnological issues, in partnership with DPED, will continue to be a vital part of planning for Hawaii's energy future.

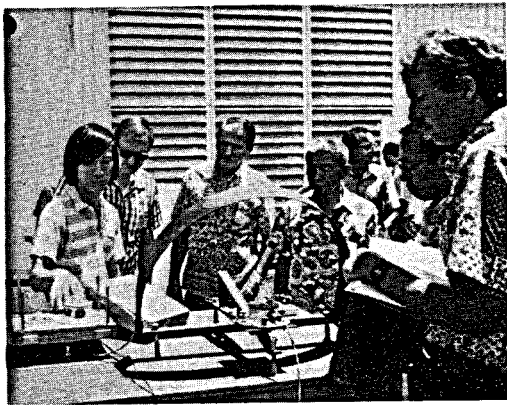


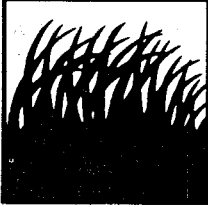
TEN YEARS OF HNEI ACTIVITIES











BIOMASS ENERGY RESEARCH

PROJECT SUMMARIES

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. Most biomass use in Hawaii today is associated with the sugar industry, which produces 10 percent of the total electricity generated in the state by burning bagasse—a by-product of sugar cane processing.

The decline of Hawaii's sugar industry and the fact that more than 60 percent of the total energy consumed in the state is liquid fuels, primarily for transportation, have made it imperative that Hawaii examine possibilities other than direct combustion. Thermochemical and biochemical processes can be used to convert biomass to chemicals and fuels such as alcohols, synthetic gases, hydrogen, and even long-chained hydrocarbons equivalent to petroleum-derived fuels. Many of these processes are in the basic research stage, although some are technically feasible, though not yet economical.

Alternative uses of idle sugar and state forest lands are being considered in HNEI's biomass energy program. A computer model that converts sugar lands to "energy plantations" is being developed. The model will consider the feedstocks, both sugar cane and other crops; the bioconversion processes and products; and total costs based on economic, social, and environmental factors.

Experimental and demonstration tree farms—originally set up to produce boiler fuel to generate electricity—may alternatively provide the feedstock for ethanol, methanol, and methane production. HNEI funds both tree farm trials and studies of the physiology and biochemistry of tree growth. One aim is to assure adequate biomass supply when commercialization of various bioconversion processes occurs.

For longer term solutions to the liquid fuels problem, fundamental research is being carried on in the Renewable Resources Research Laboratory where pyrolysis conversion processes and hydrogen production are being investigated. The laboratory's principal investigator and Coral Industries Chair professor, Michael Antal, held a workshop of pyrolysis experts in Kona to recommend appropriate research goals in the thermochemical biomass conversion.

A workshop sponsored by HNEI and DPED in fall 1984 brought together local and international authorities to develop a program to select appropriate species for biofuels conversion and to provide guidance for research, development, and commercialization options in Hawaii and the Pacific Basin. A major statewide survey will be made as part of a resource assessment program intended to determine the best species and locations for optimal yields, develop test planting programs, analyze different bioconversion methods, and determine commercialization prospects.

ENERGY TREE FARM R&D

PRINCIPAL INVESTIGATOR:

James L. Brewbaker, Ph.D.
UHM Department of Horticulture

PROJECT STAFF:

Rick J. Van Den Beldt
UHM Department of Agronomy and Soil Sciences
Alan Fox, Student Help
Paul Mello, Student Help
Charles Sorensson, Student Help

PROJECT PERIOD AND FUNDING SOURCE:

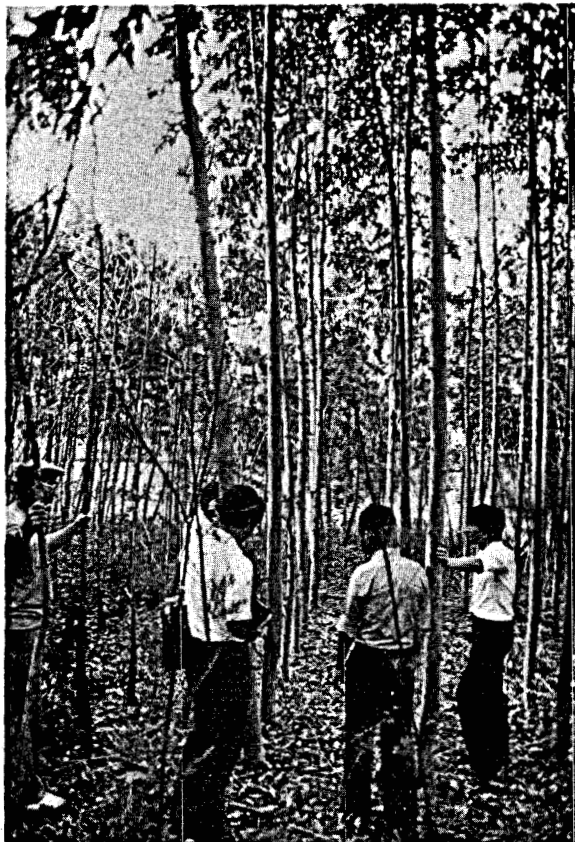
HNEI has funded this project for the third year from state R&D support.
Total funding for FY 1983-84: \$24,000

The Energy Tree Farm R&D project seeks to assess some of the primary options for biomass production in high-priority ecological zones of the Hawaiian Islands. The objectives of this project are: (1) to establish Statewide Energy Tree (SET) trials throughout the state and (2) to develop comparative data of tree farm biomass with that of herbaceous plants, notably sugar cane for bagasse, other grasses, and pineapple and other agricultural waste products.

The SET trials consist of a series of small (one-half to 5 acres), medium-term (3 to 8 years) tree plantings developed collaboratively on all major islands. Twenty of these tree farms have been planted on six islands in sites of differing soil and climate. The goals of the SET trials are: (1) to develop performance data and estimates of establishment and management costs; (2) to demonstrate capabilities and site limitations of premier tropical fuelwood tree species in diverse ecological zones; (3) to evaluate relative performance of nitrogen-fixing trees and nonfixing trees; (4) to provide fuelwood from experimental plantings for critical evaluation of density, moisture content, and caloric value; and (5) to assess productivity and values of co-products, such as leafmeal for fodder.

Data from SET trials that have been ongoing for 3 to 5 years suggest that tree farming for biomass energy will be an economic option for Hawaii's diversified agriculture. Yields of 12 barrels of oil equivalent per acre per year have generally been regarded as financially profitable in Hawaii; several of this project's trials have greatly exceeded this amount. Of course, it will not be possible to maintain experimental yields in large plantations. This bridge from experimental to "real world" wood yields will be explored further as larger plantings (SET 82-3, 83-4, and 83-6) mature.

Results of the trials thus far suggest that close spacing under plantation management can produce large amounts of biomass with excellent fuel properties. The present trials seek to provide definitive yield data, fuelwood quality data, site-adaptability variations, and recommendations for production and management practices to ensure economic returns on investment in dendrothermal power.



Visitors viewing the Leucaena at the Waimanalo Experiment Station, UH College of Tropical Agriculture.

FLASH PYROLYSIS OF BIOMASS DERIVED MODEL COMPOUNDS DISSOLVED IN A SUPERCRITICAL SOLVENT

PRINCIPAL INVESTIGATOR:

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

PROJECT STAFF:

Jiben C. Roy, Ph.D.
William Mok, M.S.
Carlos DeAlmeida, B.S.
Glen Sakima, B.S.
Sundaresh Ramayya, B.S.
UHM Renewable Resources Research Laboratory

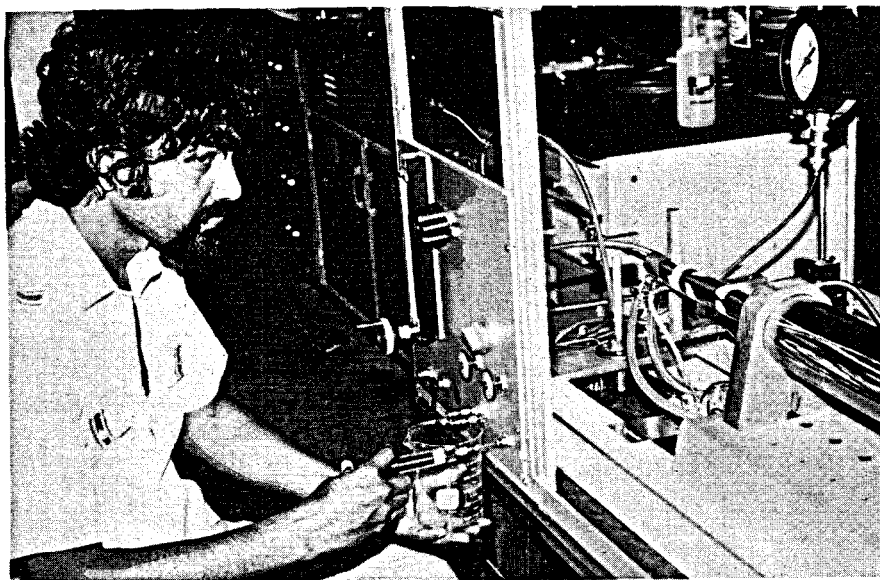
PROJECT PERIOD AND FUNDING SOURCE:

This project was funded for FY 1983-84 by the National Science Foundation (\$84,239) and the State Department of Planning and Economic Development (\$17,577). NSF funds for FY 1984-85 have been granted at \$67,533.

Many biomass derived substrates are water soluble or can be easily converted into water soluble materials. For example, sugars derived from the acid or enzymatic hydrolysis of lignocellulose, anhydrosugars derived from flash pyrolysis of holocellulose, and molasses are all water soluble. In addition, water provides a unique medium for organic reactions in its supercritical region. In supercritical water, the biomass derived monomers can decompose into a variety of gaseous fuels and chemicals. The objective of this study is to explore the decomposition of various biomass derived substrates in supercritical water using an annular, tubular flow reactor.

The fabrication of the supercritical pyrolysis reactor, including shakedown tests of the reactor, has been completed. Preliminary studies were undertaken to investigate the decomposition of glycerol and 1,3-dioxolane which mimic the reactive moieties of the water soluble anhydrosugar, levoglucosan, a primary product of cellulose pyrolysis. Tests involving the introduction of various free radical initiators, traps, and catalysts into the reaction media will be used to gain insight into the reaction mechanisms and pathways.

The experiments are expected to lead to an increased understanding of the dehydration, hydration, decarbonylation, and decarboxylation pathways of pyrolysis reactions that can result in the formation of hydrocarbons from carbohydrates.



Jiben Roy is sampling the product of the flash pyrolysis of glycerol using the supercritical tubular flow reactor.

FUEL SOURCE POTENTIAL OF HAWAII'S FOREST

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

PROJECT STAFF: Betty W. Simmerer, B.A.
UHM Department of Mechanical Engineering

**PROJECT PERIOD AND
FUNDING SOURCE:** A grant from the State Department of Planning and Economic Development for \$2,519 funded this project which ran from September 1983 through June 1984.

Although bagasse in the form of process heat for sugar mill operations and electricity generation is the largest alternative energy source in the state, biomass has even greater potential as a feedstock for the production of liquid and gaseous fuels. To assess possible sources of biomass, a study of timber stand improvement practices was initiated for the forests of Hawaii.

Timber stand improvement (TSI), as practiced on the mainland, has increased in recent years for economic and energy reasons. The logging companies began using material thinned from the forests and waste from logging and milling sawtimber, in new products which recycle this waste. New logging machinery was designed to handle smaller and cull timber.

In Hawaii, very little large-scale logging has been done because of the small land base, mountainous terrain, and watershed protection given by the forests. Investigations of tree thinning and utilization of logging and milling waste showed several differences between Hawaii and mainland forests:

1. In a tropical forest, most of the nutrients are located in the trees instead of the soil, with rapid nutrient recycling by a shallow root system. Therefore, intensive logging waste recovery would be counterproductive.
2. Hawaii, with the greatest number of endemic species of plants and animals anywhere in the world, has a unique responsibility for environmental protection. State law strictly controls logging in commercial forest land of which two thirds are under state ownership and roughly three eighths are in private ownership, but within state conservation districts.
3. Like the Pacific Northwest, most forested areas in Hawaii are found on the islands' upper slopes at grades of 20 percent or more. New thinning machinery adapted for the steeper slopes is being developed. Soil erosion is also a serious consideration on the steeper slopes.

To balance full use of Hawaii's forests for lumber and energy with protection of the state's unique biological heritage, a comprehensive body of information about forest types and locations, unique and endangered plant and animal species and their habitats, and other pertinent factors is needed. Information that has been collected should be drawn together in a more easily accessible form. A promising pilot study for Kauai using composite mapping was done by the State Department of Planning and Economic Development in 1973 (*Hawaii's Resources: Inventory and Policies, A Prototype Demonstration for the Island of Kauai*, Final Report of the State Land Resources Policy Development Project, Dept. of Planning & Economic Development, State of Hawaii, 1978). The techniques used in this study have been made obsolete by changes in computer technology. However, today's computer capabilities allow reimplementations of such a system and it is suggested that a

comprehensive geographic information system be developed that will aid in the use and protection of the state's resources.

Further work will attempt to identify areas where thinning practice might be used and will seek to locate growth information on tree types represented.

STONE AND WEBSTER ECONOMIC FEASIBILITY STUDY OF BIOMASS TO ALCOHOL PLANTS

PRINCIPAL INVESTIGATOR: Patrick K. Takahashi, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: Arthur Seki, M.S.

PROJECT PERIOD AND FUNDING SOURCE: Support of \$40,000 for this one-year project was provided equally by the State Department of Planning and Economic Development and HNEI augmenting a Solar Energy Research Institute grant of \$450,000 for the total program.

Hawaii is teamed with Stone and Webster Engineering Corporation (SWEC) to examine the technical feasibility of producing alcohol (ethanol and methanol) fuels from biomass. The three processes being studied are ethanol production by acid hydrolysis and by enzymatic hydrolysis (which break down the cellulose molecular chains into sugars using mild acid and enzymes, respectively) and methanol production by gasification.

HNEI's participation in the project involves the following tasks, performed in cooperation with DPED and SWEC: to determine markets for products and by-products, to examine the feasibility of feedstock collection and to measure its chemical characteristics, and to consider the costs of co-generation of power and steam. Site assessment studies were conducted on factors such as access to product markets, costs and availability of transportation and labor, environmental regulations affecting the site, and other applicable economic incentives.

The Big Island was selected as the site of the two ethanol projects. Both plants are designed to produce 15 million gallons of alcohol per year. The biomass feedstock in each case is wood chips from fast-growing eucalyptus trees grown on tree farms in the districts of Kohala, Hamakua, and Hilo. Approximately 20 to 30 thousand acres of land would be needed to fuel one processing plant. A continuous fermentation process will transform the sugar molecules to ethanol. These production plants also will be optimized to recycle energy for various sections of the plant. Future work includes pump design for high slurry concentrations and investigations of the kinetics of hydrolysis reaction, plant sterility, equipment life under harsh environmental conditions, and other concerns. The methanol plant, with a capacity of 7.7 million gallons per year, is designed to be modular and transportable by train. The heart of the system is based on SERI's current research with an oxygen-blown, downdraft gasifier. The feedstock in this process is also wood chips, which are burned to produce gases. The gases, in turn, are converted to methanol by use of suitable catalysts. The major concern of this project is operation of the gasifier at an up-scaled level.

COMBUSTION PROPERTIES OF BIOMASS PYROLYSIS PRODUCTS

PRINCIPAL INVESTIGATOR: Joel Fox, Ph.D.
UHM Department of Mechanical Engineering

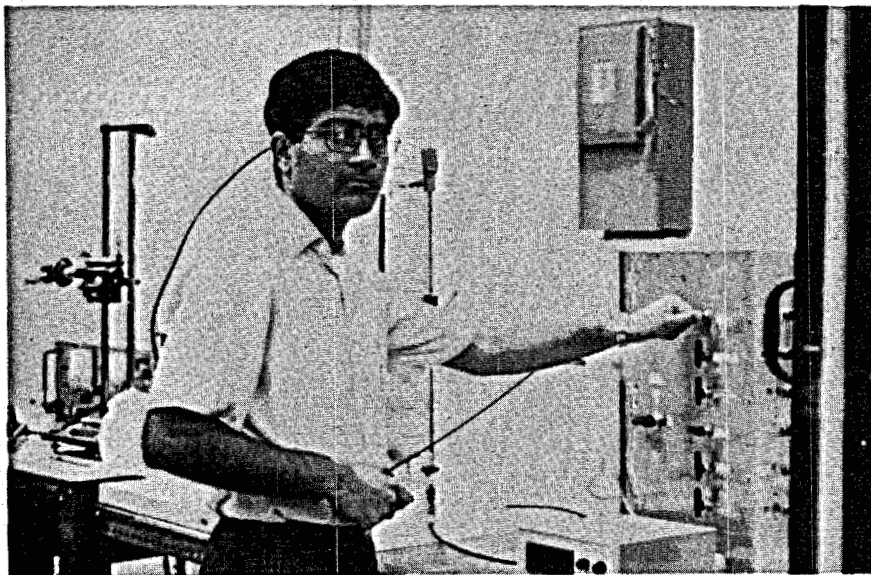
PROJECT STAFF: Ajay Bhargava, M.S.

PROJECT PERIOD AND FUNDING SOURCE: Support for this two-year project totaled \$20,500 and came from the USDOE institutional grant. Total funding for FY 1983-84: \$4,147.

It is not sufficient only to consider the production, harvest, and gasification of biomass if the ultimate goal of this resource is to produce heat or electricity. To make a case for biomass as a fuel, sufficient information must be available to analyze integrated systems, which are certain to contain combustion as a component. It is clear that data on the combustion characteristics of biomass gasification products must be an essential part of the total effort to replace all or part of Hawaii's dependence on imported oil.

Although there is a wide range of possible constituents for biomass fuel gas, a subset was segregated in which the most important components were nitrogen, carbon monoxide, carbon dioxide, hydrogen, and methane. The ranges for each gas studied were: nitrogen (39-58%), carbon dioxide (4-16%), carbon monoxide (16-20%), hydrogen (14-22%), and methane (2-6%). A gas metering system with computer-assisted manual control was used to simulate the desired mixture.

The adiabatic flame speed (or normal burning velocity) of each fuel gas mixture was determined using a burner which produced a conical flame. Experiments were also carried out in which reactant flow rate was decreased until the flame flashed back into a fully developed flow burner and the velocity gradient at the wall of the reactor was computed. Correlation equations were generated to permit the prediction of both flame speed and flashback gradient for any mixture within the range of interest. Tests of the equations indicate accuracies of $\pm 6\%$.



Ajay Bhargava initiating combustion on the biomass gas burner.

PHYSIOLOGICAL AND BIOCHEMICAL DETERMINANTS OF BIOMASS PRODUCTIVITY IN FAST-GROWING NITROGEN-FIXING TREES

PRINCIPAL INVESTIGATORS: Douglas J.C. Friend, Ph.D.
Harry Y. Yamamoto, Ph.D.
UHM Department of Botany

PROJECT PERIOD AND FUNDING SOURCE: HNEI funding of \$13,885 for FY 1983-84 from state R&D project funds was supplemented by \$9,614 from the McIntire-Stennis Company.

High yielding tree crops such as *Leucaena* are important to Hawaii as converters of solar energy to biomass fuel for generation of electricity and as a source of leaf protein for stock or chicken feed. Nitrogen-fixing trees offer the advantage of avoiding the cost of applying nitrogen fertilizers. These tree crops can also make use of land that has been taken out of sugar and pineapple cultivation and areas unsuitable for crops that demand more water and nutrients. The purpose of this research is to provide basic information on photosynthesis in *Leucaena* in order to develop a rationale for further selection of cost-efficient energy crops for Hawaii.

The photosynthesis rates of giant and wild varieties of *Leucaena* are being determined to establish whether there is a physiological basis for the high yield of the giant strain in the field. In addition, the physiological and morphological adaptations to shade are being investigated for both varieties.

In this first year of the project, three experiments were completed in which plants were grown under different levels of shading. Growth analysis methods were used to assess the yield response of the two varieties. There is no significant difference between the total biomass of the two varieties under greenhouse conditions of up to 16 weeks of growth, and they respond similarly to shade by an increase in the leaf area ratio brought about primarily by the production of thinner leaves.



Effect of shade on growth of giant Leucaena at (left to right) full sun, 40%, 20%, 10%, and 5% sun.

The effects of varying light intensities on the photosynthesis rate of attached mature leaves have been measured using the apparatus provided by HNEI funds. Data analysis is continuing and will enable calculation of the quantal efficiency of photosynthesis for the two varieties. The work will be continued in 1984-85 funded by a McIntire-Stennis grant. The photosynthetic studies will be extended to older field-grown plants, and the importance of internal mesophyll resistance for plants to adapt to the light intensity experienced during growth will be determined. The effect of shade on Hill reaction rates, a measure of the rate of oxygen release during photosynthesis, will also be investigated.

Preliminary conclusions are that the superior biomass yield of the giant variety of *Leucaena* under field conditions is probably attributable to morphological rather than physiological factors and that growth adaptation to shade is brought about by changes in leaf anatomy.

A preliminary account of the effect of radiation on photosynthesis of *Leucaena* was presented at the fifth annual meeting of Hawaii Plant Physiologists in May 1984.

ALGAL PRODUCTION RACEWAY PROJECT

PRINCIPAL INVESTIGATOR: Edward Laws, Ph.D.
UHM Department of Oceanography

PROJECT STAFF: Satoru Taguchi, Ph.D.
UHM Department of Oceanography/Hawaii Institute of
Marine Biology
Janice Hirata, B.S.
Lance Pang, B.S.
Mary Fobel, Student Help
UHM Department of Oceanography

PROJECT PERIOD AND FUNDING SOURCE: Major support of \$161,612 for the fifth year of this project came from the Solar Energy Research Institute, with HNEI contributing \$10,472 from state R&D project funds for FY 1983-84. SERI support in FY 1984-85 will be \$150,000.

Single-celled algae very efficiently convert sunlight and nutrients into carbohydrates and lipids, which can be further processed to provide liquid fuels. Laboratory experimentation on a single-celled marine alga, *Phaeodactylum tricorutum*, was initiated in 1979 to evaluate its characteristics and growth rates.

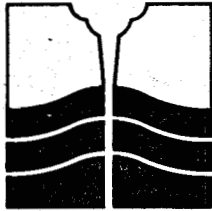
The objective of this project is to test the hypothesis that outdoor algal mass culture yields could be substantially increased by growing the algal cells in a flume, or "raceway," in which arrays of small foils suspended in the stream create systematic vertical mixing through the production of vortices. The investigators anticipate that the additional production achieved with this type of system will make microalgal mass culture an economically competitive method for producing fuels from biomass by the year 2000.

Algal production rates using conventional culture methods have never exceeded 15–20 grams per square meter (g/m^2) ash-free dry weight (AFDW) per day on a sustained basis. However, average daily yields as high as 29 g/m^2 AFDW were obtained in these raceway systems over periods as long as two weeks during the first half of 1983. Because the species being cultured at that time, the diatom *P. tricornutum*, grows very poorly at temperatures above 25°C , efforts during the last year were concentrated on finding a species that would grow satisfactorily at temperatures in the $25\text{--}35^\circ\text{C}$ range. Several promising candidates were identified and one species, *Platymonas sp.*, was tested. Over a five-month period from January to May 1984, the *Platymonas* was grown in a 48 m^2 outdoor flume without temperature control. The average daily production was 31 g/m^2 AFDW. It was also discovered that diluting the culture every three days increased daily yields into the range $40\text{--}46 \text{ g/m}^2$ AFDW. More recent work with *Chaetoceros sp.* has also resulted in daily yields of more than 40 g/m^2 AFDW.

It was concluded that yields two to three times those achieved using conventional methods can be obtained with the raceway system without temperature controls. An economic analysis indicated that removal of the temperature control restraint significantly improves the economics of the project. Investigators must establish the relevance of their research to microalgal culture in the southwestern U.S. in order to receive continued federal funding. Therefore during the next year they will test the growth of promising species in the raceway system using media similar to basic water types found in the southwestern U.S.



Algae grown in fiberglass raceways like these at Snug Harbor on Oahu could be a future source of food and fuel for Hawaii.



GEOTHERMAL ENERGY RESEARCH

PROJECT SUMMARIES

The HGP-A geothermal well, located in the Kilauea volcano East Rift Zone, was drilled to a depth of 6450 feet, and at 676°F is considered to be one of the hottest geothermal wells in the world. This single well provides 52,800 pounds per hour of 371°F and 160 psia (pounds per square inch absolute) steam to a 3-megawatt power plant, while the separated brine is discharged on the ground and ultimately recycled to the hydrological system. The HGP-A well, as of June 30, 1984, had produced a total of 47,318,000 kilowatt-hours of energy for the Big Island. Routine maintenance on the system showed very little corrosion or silica accumulation in the pipeline system, while the turbine blades were virtually free of any deposits or wear. The pressurized separator has been cleaned and the brine pipeline expanded in number for easy servicing.

The brine fluid for this well is of particular interest: about 50,000 pounds per hour of hot, pressurized brine, the equivalent of 3 barrels of oil per hour, is discarded. With the idea of recovering this valuable energy source, Governor Ariyoshi in 1984 released \$325,000 of capital improvement funds to build a geothermal research facility. The facility is currently under design, with construction expected to be completed in the summer of 1985. The purpose of the Puna Geothermal Research Facility (PGRF) is multifold. PGRF is to provide a facility in Puna for high technology research, development, and demonstration in geothermal and related activities; to initiate an industrial park development; and to examine multipurpose dehydration and biomass applications related to geothermal energy utilization.

PGRF will enable vital research and development to be conducted in both electrical and non-electrical geothermal energy applications such as dehydration, agriculture, aquaculture, by-product recovery, and others. The County of Hawaii has released \$26,500 for specific research in aquaculture and agriculture dehydration.

HNEI has formed a geothermal research advisory task force made up of representatives from the University of Hawaii, private industry, and government to advise and assist in the research activities at PGRF. In addition, HNEI has submitted proposals to the U.S. Department of Energy to examine reservoir engineering of HGP-A, ice-making and cold storage, silica recovery and utilization, sulphur removal and utilization, food processing, and hydrogen sulfide effects on native Hawaiian plants, and to initiate a technology transfer program.

Hawaiian Electric Company (HECO), which provided considerable support in the development of HGP-A and its operation, released two requests for proposals for geothermal development on the Big Island and Maui. HECO funded a study, with additional funding from HNEI, to examine the effects of hydrogen sulfide on various communities in New Zealand and has also contributed funding for the first fellowship in the Fellows in Renewable Energy Engineering (FREE) program at the University of Hawaii. This program will attract a renowned geothermal expert to lead research at PGRF.

The ultimate goal is to establish a research laboratory similar in structure to the Natural Energy Laboratory of Hawaii for ocean research, where outside researchers can use the PGRF to test their theories and equipment. The first FREE researcher will be instrumental in establishing the goals and direction of the PGRF.

The geothermal projects funded this past fiscal year reflect the interest of the utilities and government and goals of HNEI with the establishment of PGRF. A better understanding of the geothermal resource will help geothermal development in the future. Senator Richard Matsuura, Senator Mark Andrews, and Representative Andrew Levin, in particular, have expressed support for beefing up the geothermal effort for the benefit of the local community.



*Sen. Richard Matsuura
Chairman, Committee
on Energy*



*Rep. Mark Andrews
Chairman, Committee
on State Planning/En-
ergy, Ecology and En-
vironmental Protection*



*Rep. Andrew Levin
Chairman, Committee
on Higher Education
and the Arts*

SCALING AND CORROSION EXPERIMENTS WITH GEOTHERMAL HEAT EXCHANGERS

PRINCIPAL INVESTIGATOR:

Bill H. Chen, Ph.D.
UH Hilo Departments of Engineering/Computer Science

PROJECT STAFF:

Deane Kihara, Ph.D.
UHM Department of Mechanical Engineering
Arthur Seki, M.S.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE:

HNEI funded this project at \$13,848 for FY 1983-84 from state R&D project funds.

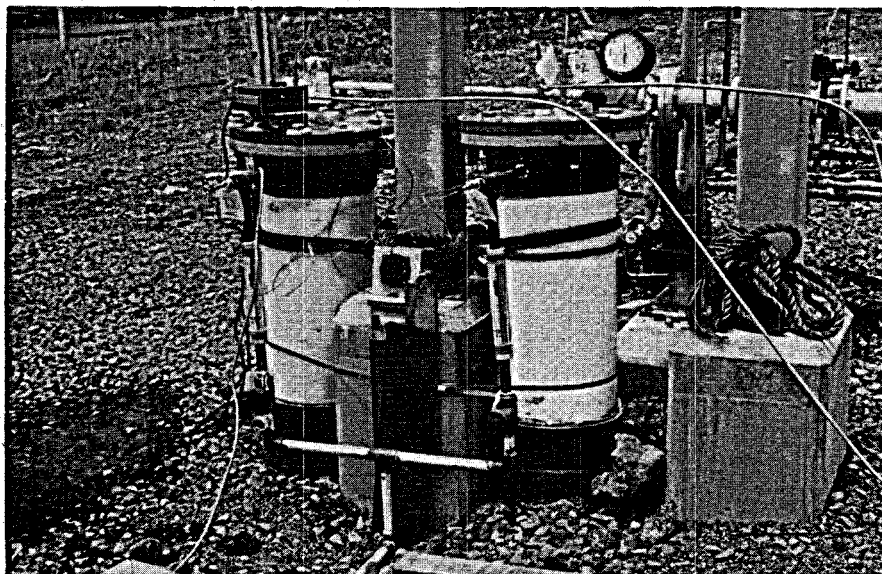
At the steam/water separator of the HGP-A Geothermal Power Plant, about 50,000 lb/hr of 155 psig, 368°F geothermal water are produced constantly. At present this water is allowed to flash to the atmosphere and is then disposed of through percolation ponds where all of the heat is lost. If a heat exchanger were employed in the waste water stream to allow the water temperature to drop from 368°F to perhaps 250°F and 15 psig, the total amount of process heat available would be approximately 6 million BTU per hour, or the equivalent of 1 barrel of oil per hour, which could be used in direct heat applications such as crop drying and food processing or even cold storage and ice-making facilities.

However, the geothermal water contains approximately 10,000 parts per million of total dissolved solids including chloride, sodium, calcium, potassium, sulfide, and silica. Of all the dissolved solids, silica has the most serious scaling potential, while chlorides and sulfides cause the most serious corrosion problem.

A bench-type coil heat exchanger with both copper and 316L stainless steel tubing was designed and constructed. The geothermal water was allowed to flow through the inside of the tubing with cooling water on the outside. Initially a two-week trial run was planned. However, after one week the control valves in the geothermal water stream were completely plugged up with silica and the experiment was delayed. A new stainless steel coil was then installed and control valves were removed from the geothermal water stream. This change eliminated the plugging problem in the geothermal water line. At this writing, the heat exchanger is undergoing an eight-week run with only the stainless steel coil. Data will be collected to evaluate the heat transfer efficiency, and the coil will be analyzed for scaling and corrosion effects. A similar run with the copper coil is planned.

As expected, the preliminary run showed higher heat exchanging efficiency with the copper coil than with the stainless steel one. However, whether the copper coil can stand the wear in the long run remains to be seen. The scale found on the inner walls of the heat exchanger tubing that was exposed to the HGP-A geothermal brines differed in the stainless steel and copper tubings. The copper tubing was coated with a very thin layer of dark siliceous scale and was underlain by a second thin layer of copper oxide and sulfide. The inner surface of the copper tubing was not badly corroded or pitted, indicating that the deposited scale acted as a protective armor against sulfide corrosion and that the scale deposit formed relatively rapidly.

The scale deposition on the stainless steel tubing was also very thin, but more uneven and rougher than that on the copper tubing. It was also amorphous silica, but it adhered more strongly to the stainless steel than to the copper, which suggests that there was no inter-layer of less firmly attached oxide or sulfide scale deposited on the stainless steel.



Stainless steel tubes being tested in hangers for corrosion and scaling in geothermal water.

SEISMIC AND THERMAL PROPERTIES OF HAWAIIAN BASALTS

PRINCIPAL INVESTIGATOR: Murli H. Manghnani, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF: Hiroki Sato, Ph.D.
John Balogh, B.S.
Eric Chun, Student Help

PROJECT PERIOD AND FUNDING SOURCE: Funds for this project came from a three-year \$82,000 NSF grant (1982-85); \$95,880 from the USDOE; and \$13,000 from HNEI's USDOE institutional grant for FY 1983-84. Funds of \$98,633 have been received from USDOE for FY 1984-85.

A knowledge of *in situ* physical and thermal properties of rocks is important for deriving thermal models of a potential geothermal system, for evaluating the seismic and heat transfer mechanisms of such a system, and for assessing the feasibility of extracting useful energy from it. The results of this project will improve developers' capabilities in geophysical exploration, assessment, and utilization of geothermal resources in Hawaii. Laboratory studies of the properties of molten rock, however, are technically difficult due to the high temperatures and corrosiveness of the melts. Investigators in this study have overcome these difficulties and developed methods to measure the combined effects of temperature and pressure, as they occur in actual geothermal environments, on the seismic and thermal properties of basaltic rocks.

The purpose of this project is to carry out laboratory investigations of seismic, velocity, and attenuation properties of compressional waves (V_p and Q_p^{-1}) of magmatic liquids of basaltic composition. The research goals are: (1) to understand how the physical, seismic, and thermal properties of basalts relevant to geothermal exploration and thermal modeling of a volcanically active area are affected by temperature, frequency, and composition; (2) to correlate the laboratory data with seismic and thermal models based on theory and field measurements; and (3) to develop a complementary spectroscopy technique, Brillouin scattering, for measuring elastic and anelastic properties of compressional and shear waves (V_p , V_s , Q_p^{-1} , and Q_s^{-1}) in relevant basaltic melts in wide ranges of composition and temperature.

Using the ultrasonic interferometric technique investigators measured velocity (V_p) and attenuation (Q_p^{-1}) in melts of several Hawaiian basalts. Systematic investigation of three types of melts (tholeiitic, alkalic, and nephelinitic compositions) were studied in the temperature range 1200-1400°C and in the frequency range of 3-18 MHz. The data fit well the Arrhenius temperature dependence with log-normal Gaussian distribution of relaxation times. V_p ranges from 2.3 to 3.1 km/sec and Q_p^{-1} ranges from 0.01 to 0.50 with decreasing temperature and with increasing frequency. The results are interpreted in terms of the viscosity values of these basaltic melts.

HNEI funds assisted researchers in developing Brillouin spectroscopy techniques for measuring velocities and attenuation of both compressional and shear waves (V_p , Q_p^{-1} , V_s) and Q_s^{-1} in molten basalts and related liquids. The V_s and Q_s^{-1} data are needed to deduce important thermodynamic properties of such melts.

Thermal diffusivity and its temperature dependence were measured for several types of Hawaiian basalts. Using the measured diffusivity and specific heat data, investigators deduced the thermal conductivity of basalts as a function of temperature.

INERT GAS ABUNDANCE PATTERNS AS GEOTHERMAL TRACERS

PRINCIPAL INVESTIGATORS:

Donald M. Thomas, Ph.D.
Hawaii Institute of Geophysics
John Naughton, Ph.D. (Emeritus)
UHM Department of Chemistry

PROJECT STAFF:

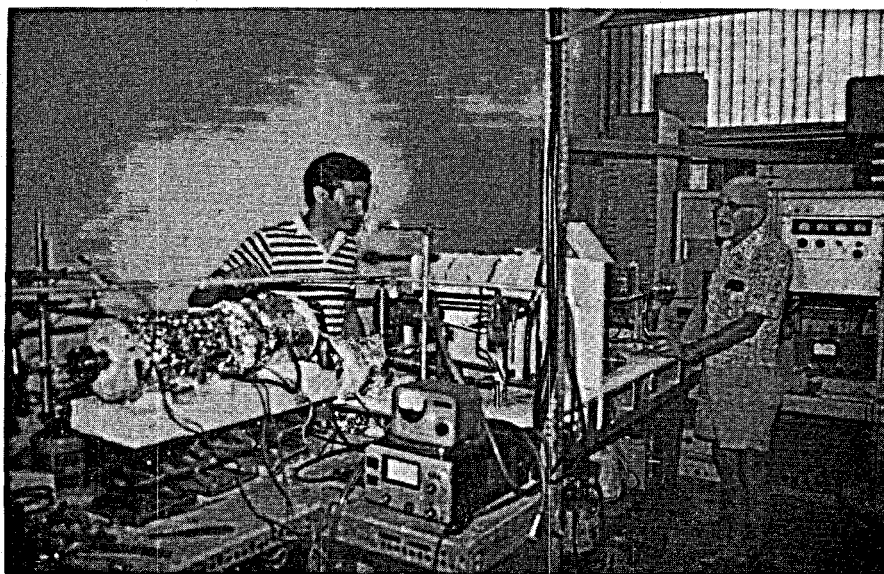
Stephen Anthony, B.S.
Hawaii Institute of Geophysics

PROJECT PERIOD AND FUNDING SOURCE:

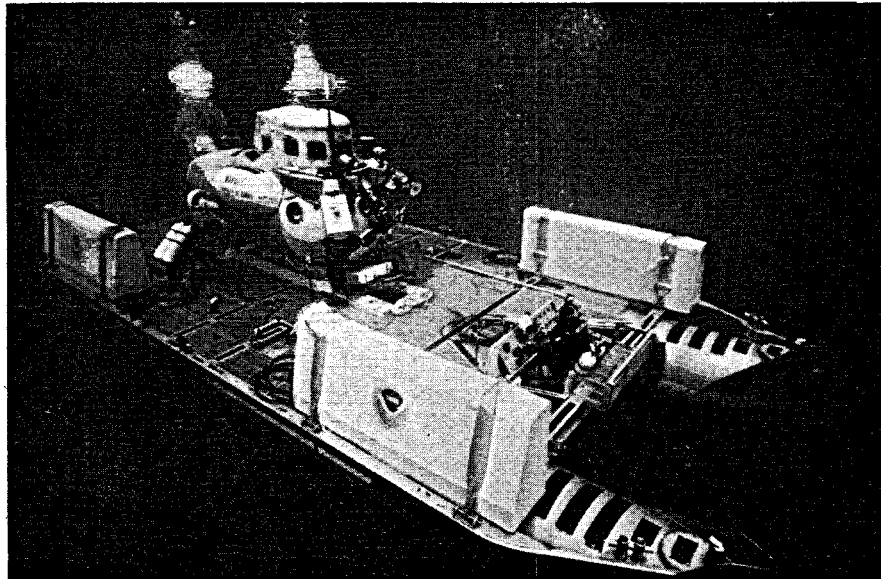
Total funding for FY 1983-84: \$5,427. Second year by state project support.

This project was designed to evaluate the relative abundance ratios of the inert gases (helium, neon, argon, krypton, and xenon) present in geothermal fluids, as well as the isotopic abundances of these gases. It is recognized that the atomic and isotopic ratios of these gases vary widely between atmospheric gases, gases dissolved in cold groundwaters, gases dissolved in geothermal fluids, and gases present in magma bodies. The overall intent of this research was to use the abundance and isotopic ratio differences as a means of predicting various geothermal resource parameters. The major utility of these data to the future of geothermal development in Hawaii lies in evaluating the probable quality of a geothermal resource after a geothermal well is drilled.

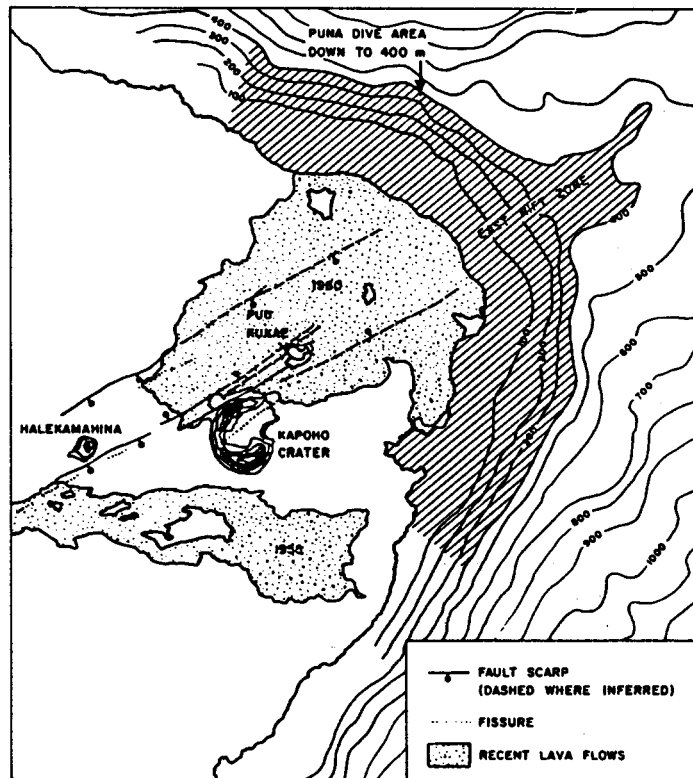
The work conducted on this project during the last year was directed toward debugging and improving the mass spectrometer used for isotopic and abundance measurements on geothermal and fumarole gases from the island of Hawaii. Although considerable progress was made and a limited number of samples were analyzed, instrumental difficulties continued to forestall the acquisition of any significant research results. The primary problems encountered were associated with electronic malfunctions and vacuum system leaks; all were attributable to the age of the equipment. The assessment of the investigators is that a great deal of time and money would be required before this equipment would be sufficiently reliable to yield useful research results. They decided on that basis to suspend efforts to acquire further data until sufficient extramural funds become available to complete the needed instrument modifications.



Donald Thomas (left) and John Naughton with mass spectroscopy equipment.



The Hawaii Undersea Research Laboratory submersible Makali'i is used to study undersea hydrothermal activity. The Makali'i is being released by support divers from its launch, recovery, and transport platform.



Location of Makali'i survey area (hachured) on the upper portion of the submarine East Rift Zone. Bathymetric contours in meters. Recent lava flows, fault scarps and fissures along the axis of the rift zone are shown.

HYDROLOGY, CHEMISTRY, AND MICROBIOLOGY OF GEOTHERMAL SYSTEMS ON THE SUBMARINE RIFT ZONES OF THE HAWAIIAN CHAIN

PRINCIPAL INVESTIGATOR: Gary M. McMurtry, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF: David Epp, Ph.D.
Hawaii Institute of Geophysics
David M. Karl, Ph.D.
UHM Department of Oceanography

PROJECT PERIOD AND FUNDING SOURCE: HNEI funding of \$10,231 for FY 1983-84 came from the USDOE institutional grant and supplemented Sea Grant Program funds of \$37,000. Sea Grant will continue to support the project at \$47,000 for the next fiscal year.

This project has several major objectives: (1) to search for submarine springs, hot or cold; (2) to explore for evidence of submarine hydrothermal activity and ore deposition; (3) to explore for recent submarine eruptive activity; and (4) to map the submarine morphology of the East Rift Zone of Kilauea Volcano. Techniques in this project are primarily observational, using the Hawaii Undersea Research Laboratory (HURL) submersible *Makali'i*. The *Makali'i* is equipped with video cameras and recorders, 35 mm color photography capability, an environmental monitoring package, and a thermistor probe mounted onto the manipulator arm of the submersible. In this eleven dive sequence, exploration was extended to the areas offshore of Pohoiki and Opihikao on the Big Island, where coastal hot springs are found. Efforts were also continued at Cape Kumukahi with the new HURL tracking and navigation systems. Dives at Opihikao revealed large sediment-covered, steep submarine slopes and a possible thermal anomaly. At Pohoiki several large a'a lava flows extended to about 600 feet, with steep sediment fans in between. A possible lava tube or cave was discovered at about 600 feet which appeared to be slowly emitting cold water. This tube and other similar features were found at the terminus of long a'a flows. Water samples were collected for chemical analysis.

Mapping dives were continued with greatly improved navigation at Cape Kumukahi. Eruptive sites were rediscovered at about 1100 feet and sampled. These sites were small and scattered, with reddish basalt alteration and copious fresh pumice in small mounds. A correlation with the seaward extension of the northern East Rift Zone graben fault is suggested. The dominant geology at the Cape is large a'a/pahoehoe flows running downslope parallel to the axis of the East Rift Zone. Very little sediment (carbonate-rich coral debris) is evident between flows but large sediment fans were noted north and south of the rift axis. A large lava tube was found at 1100 feet and a water sample was collected. No water egress was apparent. In general, freshwater egress from 200 to 1200 feet is apparently uncommon in the areas studied. This may be due to diffuse discharge or extremely localized flow.

INVESTIGATION OF THE SODIUM/LITHIUM GEOTHERMOMETER FOR HAWAIIAN GEOTHERMAL SYSTEMS

PRINCIPAL INVESTIGATORS: Eric H. DeCarlo, Ph.D.
Donald M. Thomas, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF: Joan McCullough, B.S.

PROJECT PERIOD AND FUNDING SOURCE: This project was funded for FY 1983-84 from the USDOE institutional grant at \$9,507. A grant of \$213,000 is pending from the National Science Foundation to continue geochemical studies of the Kilauea East Rift Zone.

A major application of geochemical principles can be found in the use of chemical species as geothermometers for geothermal exploration. Most geothermometers used to date have provided suitable temperature estimates for high-temperature waters tapped by deep drill holes. However, numerous departures from ideal behavior have been observed in natural springs, steam vents, and a variety of surface or near-surface expressions of geothermal systems. Generally these problems arise from reequilibration of the various species upon ascent from the geothermal reservoir. Since Hawaii does have these problems, none of the geothermometers proposed to date has been quantitatively suitable.

The purpose of this investigation is to evaluate the applicability of the sodium/lithium (Na/Li) cation pair as a quantitative geothermometer in Hawaiian geothermal systems. This ion pair is reported to be unaffected by reequilibration processes and should provide information on deep reservoir temperatures, even in wells and springs diluted with meteoric/nongeothermal waters.

A series of separated brine samples collected at HGP-A between 1981 and 1984 was analyzed for alkali and alkaline earth cations (Na, Li, K, Ca, Mg), as well as for chloride and the trace elements, iron and aluminum. In addition, samples were collected and analyzed from wells and springs in the Puna area known to have geothermal components and from West Maui in areas suspected to be affected by a deep residual heat source from the West Maui Volcano. For the data obtained from all these samples, various ion pair ratios, such as Na/Li, Mg/Ca, Li/Cl, Na/Cl, were calculated. A computer program was used to correct for seawater intrusion into the reservoir and to calculate enrichments or depletions of various species investigated as compared to the seawater component of the system at HGP-A.

The 1981-1984 series of more than 50 samples of HGP-A separated brines has been analyzed, and continued monitoring of the brines is under way to follow trends observed to date. Calculations of the various ion pair ratios have led to some interesting observations.

The Na/Li ratio was not found to follow the calibrated geothermometric equation proposed by other researchers. However, the data for Hawaiian water do yield a consistent relationship with temperature, indicating that the Puna area and West Maui waters have either a single source of thermal water or a similar regime in their thermal evolution. Additionally, the data show conclusively that the seawater recharge component at HGP-A has increased progressively with time and is continuing to do so. Values for the Mg/Ca ratio at HGP-A have not changed significantly with time and compare extremely well with those for other high temperature geothermal areas of the world.

NUMERICAL MODELING OF GROUNDWATER IN THE EAST RIFT ZONE OF KILAUEA, HAWAII

PRINCIPAL INVESTIGATOR:

David Epp, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF:

Clark C.K. Liu, Ph.D.
Department of Civil Engineering
Gary McMurtry, Ph.D.
Frank Peterson, Ph.D.
Jewelle Imada, B.S.
Hawaii Institute of Geophysics

PROJECT PERIOD AND FUNDING SOURCE:

The third year of this project was funded by state R&D funds at \$7,676. Further funding is pending from the State of Hawaii Department of Health.

There is considerable interest in the geothermal potential of the Puna district on the Island of Hawaii. Although extensive studies have been undertaken to assess this potential, relatively little is known about the hydrology of Puna. Examination of the interrelationships between groundwater flow, water temperature, and water chemistry is necessary to accurately describe the groundwater system. Such knowledge is essential to fully assess and utilize the geothermal resources of the area.

The major objectives of this study are twofold: first, to gain insight into the existing condition of groundwater hydrology in the geothermal area of Puna, and second, to determine the effects of the disposal of geothermal effluent on the groundwater.

The initial phase of the study concentrated on the collection of available information on the hydrology, geology, meteorology, geochemistry, and temperature of groundwater in the area. In the next phase a numerical model that simulates the hydrologic conditions of Puna was developed. Calibration and verification of the model were accomplished using well water data. This model computes a water budget using mass balance, thus providing an estimate of water quantity that is constrained by available geohydrological data. Once calibrated, the model was used to investigate the effects of geothermal effluent on the shallow groundwater and to evaluate the distribution of this effluent over time.

The results of this study provide a means to examine long-term effects of future geothermal development on the groundwater resources in the area and give some insights into the mechanisms controlling the chemistry of the Puna wells.

The calibration of the model identified the major factors controlling the hydrology of Puna. The most important factor is the East Rift Zone. The upper portion of the rift has low permeability, which makes it much more effective as a water barrier and causes large head gradients to form. Another major influence on the groundwater flow in the area is heat. High temperature and, therefore, high dynamic viscosities caused estimates for the hydraulic conductivities to be much higher than normally estimated for Hawaiian basalts. The higher temperatures also caused the amount of vertical mixing to increase, and thus the dispersions to be much larger than normally estimated.

A water budget was calculated for the area, including the recharge from precipitation, discharge from the wells, and discharge to the ocean. Once the model was calibrated, the effects of the seepage of geothermal effluent into the groundwater system were examined by injecting geothermal effluent of a specified concentration into the aquifer and calculating the chloride distribution at the end of a 25-year period. The simulations showed that the consequence of the injection of geothermal effluent is a direct function of the salinity of the effluent. If the chloride concentration in the effluent is high, effluent seepage might cause long-term water quality problems, although the model calculations may have been unstable at high concentrations.

The model was further tested by comparing the results of the simulations with chloride concentrations measured in Puna water wells, test holes, and coastal springs during 1981. As expected, the major changes in salinity occurred south of the rift and to the northeast of HGP-A. Three major changes occurred during 1981: GTW-3 (2982-01) showed an increase in chlorides of about 1514.7 ppm (8.2% of the salinity of seawater); Allison (2281-01) showed an increase of 601.3 ppm (3.35%); and Malama-ki (2783-01) showed a decrease of 1736.0 (9.4%). The changes in the chloride concentrations were greatly underestimated by the model.

Investigators noted that the many assumptions made in this modeling study limited the accuracy of the results. The model was the first attempt to incorporate the effects of groundwater flow, chemistry, and temperature in a numerical model for Puna.

SHALLOW MAGMA CHAMBERS AND GEOTHERMAL POTENTIAL OF THE HALEAKALA SOUTHWEST RIFT ZONE

PRINCIPAL INVESTIGATOR: John M. Sinton, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF: JoAnn Sinton, B.S.
Alex Strange, Student Help

PROJECT PERIOD AND FUNDING SOURCE: Funding of \$9,938 for FY 1983-84 came from the USDOE institutional grant.

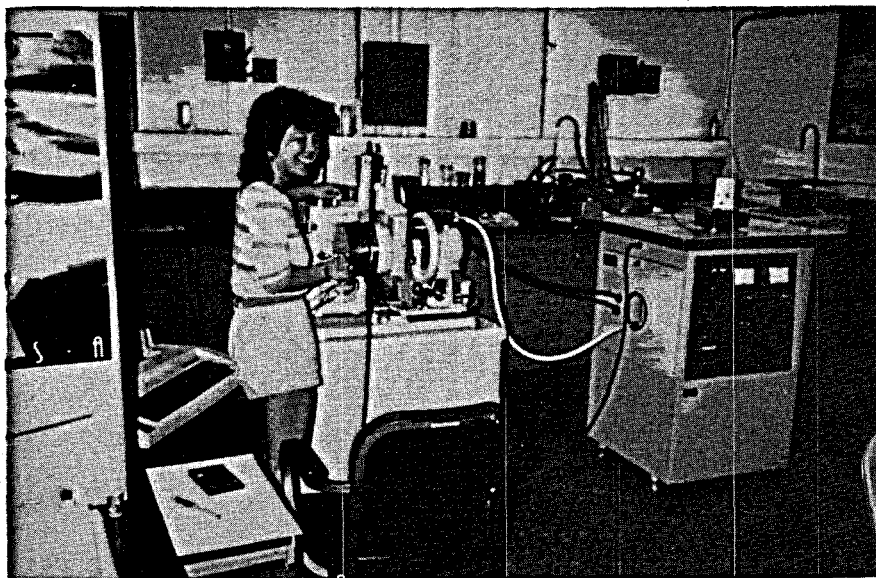
A project to investigate the possibility of shallow heat reservoirs in the form of present or residual magma chambers beneath the Southwest Rift Zone of East Maui (Haleakala) Volcano on the island of Maui was begun in summer 1983. The investigation involved the mapping and collection of products of all Hana Series eruptions in order to determine the general age relations of eruptions on the rift zone. Collected samples were then studied in order to assess the degree of differentiation of samples through time and variations along the rift axis and, hence, the presence or absence of shallow chambers in which such differentiation might have occurred.

A total of 35 eruptive events of the Hana Volcanic Series, the youngest series on East Maui Volcano, were identified and mapped, extending from Haleakala summit to the coast of Keoneoio. For ease of analysis the samples were divided by location into six major rift axis eruptive centers that have been the locus of four to six eruptions each, and a seventh category for off-axis eruptions. Within each division, eruptions were evaluated for age (i.e., a crude chronology was established for each of the six major rift axis centers) and for degree of differentiation.

Stratigraphic studies showed that there have been at least six eruptions on the Southwest Rift Zone in the last 1000 years, the last about 1790 A.D. The age of eruptions do not vary systematically with position along the rift axis; the eruptions are scattered more or less along the entire rift. At least four of the youngest eruptions occurred on the lower rift zone in regions that might be hydrologically favorable for a geothermal resource to be present. Six eruptions in the last 1000 years give an eruption frequency of less than one every 165 years. Since the last eruption occurred about 195 years ago, the Southwest Rift Zone can be considered to be overdue for an eruption. However, based on this recent history, it is not possible to predict where the next eruption is likely to occur.

Based on petrography, the most differentiated samples have erupted from the two middle major centers. The combination of some very young activity and some slightly older but significantly differentiated lavas from the Makua center makes this region one of the best for the development of a geothermal resource. In the uppermost and lowermost sections of the rift, crystal-rich recent lavas suggest eruption from a largely crystallized part of a magma chamber, and therefore that any chambers underlying these areas may be waning.

There are no direct indications of latent heat in the form of thermal groundwater or warm ground anywhere along the Southwest Rift Zone, and the rift zone is seismically inactive. These data strongly suggest that sizeable magma chambers in the shallow subsurface are almost certainly lacking. The petrography of the Southwest Rift Zone lavas is consistent with derivation from fairly deep chambers and thus even the most differentiated samples do not require shallow chambers.



Technician JoAnn Sinton in the HIG x-ray fluorescence laboratory where chemical compositions of rock samples are determined.

BIOLOGICAL ABATEMENT OF HYDROGEN SULFIDE DURING GEOTHERMAL ENERGY PRODUCTION

PRINCIPAL INVESTIGATOR: David M. Karl, Ph.D.
UHM Department of Oceanography

PROJECT STAFF: Kim Orrett, M.S.
Christopher D. Winn, Ph.D.

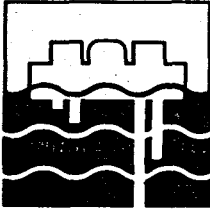
PROJECT PERIOD AND FUNDING SOURCE: The USDOE institutional grant provided funding of \$17,813 for the first year of this project.

Microbiological abatement of hydrogen sulfide emissions from geothermal wells may offer advantages over current chemical methods: (1) the by-product of biological oxidation may be a chemically useful substance; (2) hydrogen sulfide removal efficiency may be greater; and (3) energy released upon oxidation may have further economic uses.

The purpose of this research is to evaluate the potential for developing a microbiological hydrogen sulfide abatement system for use in Hawaii's geothermal energy production industry. The specific research objectives are to isolate a variety of sulfur bacteria from geothermal environments on the Big Island; to characterize their growth properties with regard to potential application as geothermal sulfide scrubbers; and to construct a laboratory model of the geothermal discharge system to evaluate the efficiency of bacterial growth under simulated *in situ* conditions.

A new laboratory was set up for this project, which involved acquiring experimental equipment and developing methodologies to isolate sulfide-oxidizing bacteria from a variety of sources and maintain them in laboratory culture. However, attempts to isolate sulfide-oxidizers from Hawaii geothermal sources were unsuccessful and it was necessary to obtain sulfide-oxidizing bacteria from a number of other sources. Initially four or five separate bacterial strains were isolated and two of these strains, which show the greatest difference in metabolic characteristics, were selected for detailed examination in chemostat culture. Both strains selected are obligate sulfur-oxidizers and show excellent growth when cultured.

Growth characteristics of these two organisms in chemostat culture will be compared and their potential use in a biological sulfide abatement system in Hawaii geothermal wells will be evaluated in three to five more months of laboratory work. Continuation of this project promises to yield interesting data on the growth of sulfide-oxidizing bacteria and has the potential to provide an important new technology for the state's developing geothermal industry.



OCEAN ENERGY RESEARCH PROJECT SUMMARIES

Ocean thermal energy conversion (OTEC) uses the temperature difference between the deep cold water and the warm surface water to generate electricity and produce fresh water. The cold water effluent is additionally a valuable resource for aquaculture applications. Hawaii has invested considerable resource towards advancing this concept.

Since the heat exchanger costs are the largest single item in a closed-cycle system and the temperature difference is small relative to fossil fuel power plants, much attention has been given to optimizing effectiveness by controlling corrosion and biofouling. At the Seacoast Test Facility on the grounds of the Natural Energy Laboratory of Hawaii (NELH) at Ke-ahole Point, Hawaii, research is addressing the effects of corrosion and biofouling on heat exchanger performance. Various metals, conduit shapes, and methods for controlling biofouling have been under examination. A key finding from this research is that biofouling does not occur in the cold water stream.

Other components are also under investigation, such as the cold water pipe deployment offshore of Waikiki beach and Ke-ahole Point to examine the various forces on the pipe. Similarly, materials for the deep sea electric cable are being examined for anticorrosive and electrical conducting properties.

A second OTEC cycle gaining support is the open-cycle system, where the warm surface water is vaporized in a vacuum, producing steam which drives a turbine to generate electricity. If fresh water is desired as a by-product, then a surface type heat exchanger is necessary.

In conjunction with the open-cycle evaporator-condenser research, investigators from J.K.K. Look Laboratory have been monitoring the concentrations of various dissolved gases in seawater and their ease of removal with different levels of vacuum pressure. Tests have been proposed to examine the effects of evaporator-condenser performance with different levels of deaerated seawater.

The effluent from these systems are being examined in various ways. In aquaculture research scientists are examining the cold water's value for growing nori (a seaweed), trout, salmon, Maine lobster, abalone, and strawberries. The positive results from the preliminary tests of an abalone project have led to commercialization of this product at NELH. Other researchers are studying the potential effects of large OTEC effluent discharges on the ocean life. The introduction of warmer or cooler water and nutrient rich water may have significant effects on the ocean life cycle.

The original research goals set by the U.S. Department of Energy for large megawatt-size power systems have been reduced to focus on 1 to 10 megawatt size plants for small island communities. The research projects supported by HNEI for the 1983-84 fiscal year have enhanced the research efforts set forth by USDOE.

OPEN-CYCLE EVAPORATOR EXPERIMENT

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

PROJECT STAFF: Hans-Jurgen Krock
 J. K. K. Look Laboratory of Oceanographic Engineering
 Arthur Seki, M.S.
 Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: USDOE through the Solar Energy Research Institute and HNEI jointly funded this project during FY 1982-83. Funds have been renewed at \$258,541 for 12 months beginning August 1984.

Ocean thermal energy conversion systems present a unique opportunity to provide not only electricity, but also hydrogen and hydrogen-derived fuels such as ammonia and methanol, as well as a by-product of fresh water. Until recently U.S. Department of Energy research has focused on closed cycle OTEC because it was considered to be close to commercial feasibility; but research attention and government funding are increasingly turning to open cycle OTEC systems. SERI, which has been conducting its own freshwater open cycle laboratory experiments, is also funding this seawater experimental project in Hawaii at NELH, the Natural Energy Laboratory of Hawaii at Ke-ahole Point on the Big Island, the only facility in the world with adequate installed supplies of warm surface water and cold deep ocean water.

In open cycle, the working fluid is seawater. Warm surface water is evaporated in a vacuum, producing low-pressure steam. The steam is then expanded in a large turbine to produce electricity and finally condensed back to liquid using deep cold seawater.

This project constitutes the first experiments with open cycle ocean thermal energy conversion since the original experiment by Claude in the 1930s. Only preliminary experiments were conducted, since most of the time and money were spent on constructing the apparatus, installing the equipment at NELH, troubleshooting the vacuum and water supply systems, and acquiring the necessary measuring equipment.

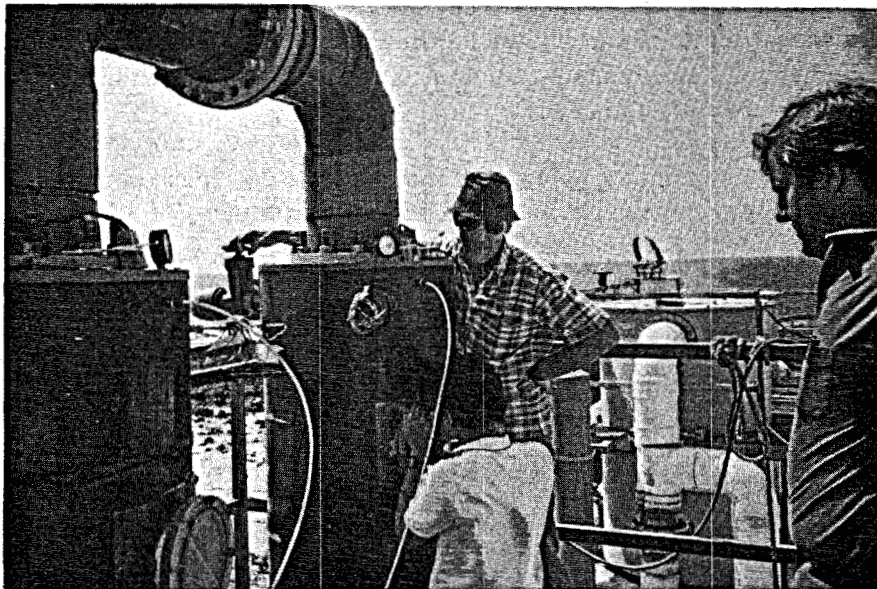
Experimental objectives were: (1) to perform initial tests with seawater to determine whether unforeseen problems such as foaming or excessive release of noncondensable gases would rule out further development; (2) to perform tests on evaporator and condenser efficiency as a function of size, configuration, etc.; (3) to obtain sufficient operating experience to draw up a fully developed research plan; and (4) in the long term, to develop the baseline data needed for design of an OC-OTEC pilot plant.

The test system consists of separate evaporator and condenser tanks, each with a single-spout configuration, mounted on the top deck of the cold water header tank tower at NELH—approximately 34 feet above mean sea level. The units have observation ports, drain and inlet lines, temperature and pressure measurement points, and are interconnected by a short 12-inch diameter PVC "gooseneck." The instrumentation for this project includes flowmeters, temperature sensors, and a pressure transducer. Data are collected by an HP-41CV calculator through a multiplexer and displayed on a thermal printer.

Preliminary results of the experiments performed show that foaming is not a problem, and no technical problems have surfaced that would make the OC-OTEC cycle infeasible. Thus, the experiment has accomplished its purposes. The results and the operating experience are being used as a basis for developing more detailed experimental plans for the proposed next phase of work.

The current vertical spout condenser configuration is extremely inefficient, therefore, parametric investigations using various spout diameter/heights will be kept to a minimum. Additional data will be obtained in the vacuum exhaust line coupled with further dissolved gas measurements to obtain mass and energy balances in the system.

In a related project also funded by SERI, Hans Krock, Director of Look Laboratory, is investigating a packed column deaerator, which would remove noncondensable gases from OTEC water before it reaches the evaporator. Once the present evaporator/condenser system is considered functional, it will be operated in series with the deaerator and experiments will quantify the effects of deaeration on evaporator/condenser performance.



Jorn Larsen-Basse (in hat) with open cycle apparatus at NELH.

ELECTROCHEMICAL MEASUREMENTS OF CORROSION AND BIOFOULING FILMS ON SIMULATED OTEC HEAT EXCHANGERS

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

PROJECT STAFF: Patrick K. Sullivan, M.S.
UHM Department of Ocean Engineering

**PROJECT PERIOD AND
FUNDING SOURCE:** This project has been funded since 1981 through USDOE/
Argonne National Laboratories and the Sea Grant Program
at \$86,524. HNEI provided state R&D project funds in
FY 1983-84 of \$8,478.

Heat exchanger technology is fundamentally important to the practical development and economical use of an OTEC facility. Potential impacts of this research are widespread although they are of particular concern to aluminum companies interested in producing heat exchangers. An estimated savings of \$70 million could be realized for a 40 MW OTEC plant if aluminum rather than titanium were used for its heat exchangers.

Electrode impedance spectroscopy (EIS) is a new technology that nondestructively monitors the condition of heat exchangers, including corrosion kinetics, localized corrosion, and biofilm formation. It is a diagnostic tool that allows continuous nondestructive and *in situ* heat exchanger monitoring by observing the steady state response to a small amplitude sinusoidal perturbing potential imposed on the heat exchanger material.

In this project, EIS technology was used to make electrochemical measurements of corrosion and biofouling films. From the change in the phase and amplitude of the response signal at various frequencies, a frequency response spectrum can be constructed from which various equivalent circuit elements representative of the fouling film can be determined.

Three materials are currently under investigation at the Natural Energy Laboratory of Hawaii using EIS. These are copper-nickel 90:10, commercially pure titanium, and aluminum-clad 3003. Tests are made using specially designed EIS corrosion cells placed in flowing seawater. Results are compared with heat exchanger material coupons similarly placed in flowing seawater.

Data are still being collected. Preliminary results indicate the following:

1. Corrosion rates can be determined at low frequencies on the EIS plot.
2. Changes resulting from biofouling occur at high frequencies on the EIS plot.
3. The occurrence of localized corrosion can be identified.
4. The formation of multiple films can be identified.
5. The effect of cleaning the surface of the material can be determined quickly.
6. Alclad 3003 may exhibit localized corrosion; however, it later develops a protective film which results in a corrosion rate similar to that of titanium.

NITROGENOUS PRODUCTS OF OTEC CHLORINATION AND THEIR POTENTIAL EFFECTS ON OTEC AQUACULTURE

PRINCIPAL INVESTIGATOR:

Francis J. Sansone, Ph.D.
Hawaii Institute of Geophysics
UHM Department of Oceanography

PROJECT STAFF:

Peter N. Sedwick, B.S.
Nolli K. Silva, Student Help
UHM Department of Oceanography

PROJECT PERIOD AND FUNDING SOURCE:

The third year of this project was funded at \$11,877 from the USDOE institutional grant. Funds to continue this research are being sought from USDOE and the Environmental Protection Agency.

A major problem facing designers of OTEC power plants is the necessity of keeping heat exchanger surfaces free of fast-growing biofouling films, which retard heat transfer and lower plant operating efficiencies. Chlorination is an effective means of controlling biofouling on submerged surfaces, but chlorination of marine waters may produce halogenated organics, many of which have been shown to exhibit mutagenic, carcinogenic, or cytotoxic properties and may be accumulated by aquatic organisms.

The objective of this project is to identify the major nitrogenous products resulting from chlorination of tropical seawater in order to predict the environmental effects of different chlorination treatments used to control biofouling in OTEC power plants. The focus of this year's research has been the chlorination products of aqueous free amino acids, since these amino acids comprise more than 10 percent of the dissolved organic nitrogen in seawater at Ke-ahole Point, the OTEC research site.

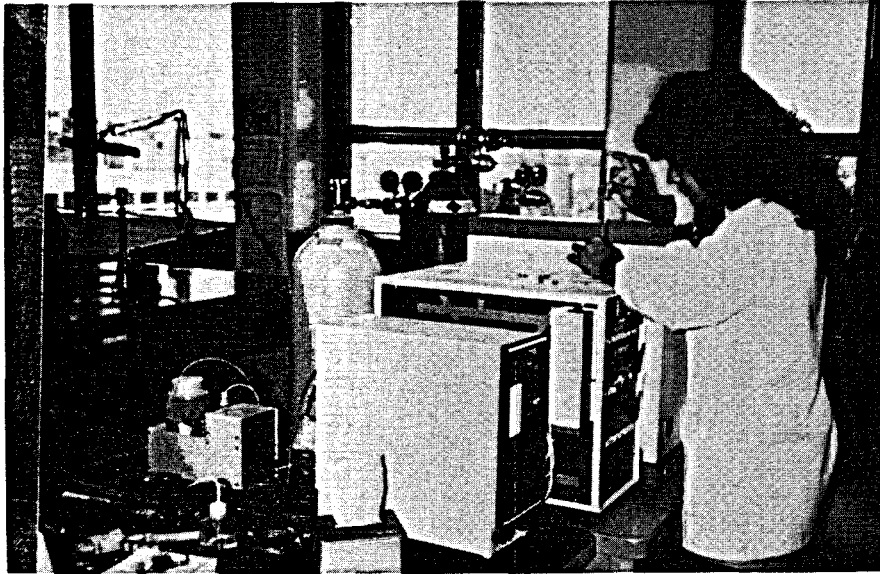
Researchers specifically studied the production kinetics of several nitrogenous organic compounds formed during the chlorination of aqueous solutions of alanine (a common amino acid in seawater) in ratios comparable to OTEC chlorination conditions. These compounds were separated with a novel liquid-liquid solvent extraction and capillary gas chromatographic technique and were characterized by mass spectrometry.

A major stable chlorination product of alanine is acetonitrile (CH_3CN), a toxic compound which forms rapidly, particularly in the presence of bromide, an important constituent of seawater. However, the low levels of acetonitrile that would be produced through OTEC chlorination were not judged to be a serious environmental threat.

Time course experiments were also conducted on the chlorination of aqueous methylamine in the presence or absence of bromide at room temperature. Formation of several methyl halamines in the presence of bromide is rapid, with little observable change in their concentration over times as great as 24 hours. Results suggest that reactant concentrations are critical in determining the relative amounts of different methyl halamines formed.

Attempts were made to measure the concentration of methyl halamines in several chlorinated Hawaiian seawaters, but they were undetectable except for the moderately polluted waters of Kewalo Basin, Oahu. Since OTEC plants will use comparatively pristine seawater, the production of methyl halamines from OTEC chlorination is not expected to pose a significant environmental problem.

Chlorination products of three other common seawater amino acids, valine, leucine, and isoleucine, are currently being studied. The results from these experiments should allow a reasonable estimation of the potential environmental effect of OTEC chlorination due to the halogenation of free amino acids present in seawater.



Nolli Silva analyzes OTEC chlorination samples by gas chromatography.

DYNAMIC POSITIONING OF A FLOATING OTEC PLANT USING ENVIRONMENTAL FORCES

PRINCIPAL INVESTIGATOR: John P. Craven, Ph.D.
UHM Department of Ocean Engineering

PROJECT STAFF: Sreekumar Thampi, B.S.

PROJECT PERIOD AND FUNDING SOURCE: Support of \$7,405 for this project in FY 1983-84 came from state R&D funds.

One design under consideration for Hawaii is a floating plant with a long cold water pipe reaching into the ocean depths. To keep this type of plant in position, some type of station-keeping system is necessary. In USDOE sponsored programs, three methods of station-keeping have been studied: static mooring, dynamic positioning, and a combination of both.

If an OTEC plant is designed to move over the ocean surface, or "graze," then mooring cannot be used and a means of dynamic positioning must be found. In the USDOE studies, dynamic positioning using conventionally powered propulsion devices was found to be impractical due to the power requirements. If a method of positioning an OTEC platform using natural forces, such as wind, waves, and current, can be found, then dynamic positioning will be a viable alternative to mooring for position control.

The research objectives of this project are to investigate the possibility of dynamically positioning an OTEC plant using the forces available from ocean currents. A conceptual 40 MW plant with two large lifting surfaces attached to the cold water pipe was studied using a steady state analysis of the lift and drag forces generated by the lifting surfaces to determine if the plant will sail against a surface current. The two lifting surfaces in a current gradient are analogous to the sail and keel of a sailboat and sailing against the current is analogous to tacking with a sailboat.

The research effort was divided into two major tasks. The first was to find the steady state velocity of the platform for various vane settings with a specified current profile and then to determine if the platform could be turned from moving downstream to moving upstream using a quasi-steady state analysis of the turning dynamics. The second task, still in progress, was to perform a non-steady state dynamic analysis of platform forces and motion that includes both computer and physical modeling of the system.

The analysis shows that the concept is theoretically feasible, that the system can have an upstream velocity component and is able to turn from a downstream drift to an upstream tack, therefore staying within a watch circle. Preliminary structural calculations indicate that forces and moments can be accommodated. Future work will involve non-steady state analysis of the equations of motion of the pipe/platform and physical modeling.

POTENTIAL EFFECT OF OTEC WASTE WATER ON NATURAL PHYTOPLANKTON ASSEMBLAGES

PRINCIPAL INVESTIGATOR: Satoru Taguchi, Ph.D.
UHM Department of Oceanography

PROJECT STAFF: David Jones, M.S.

PROJECT PERIOD AND FUNDING SOURCE: Support for the one-year project was provided by the US DOE institutional grant. Funding to continue this research is pending from the Sea Grant Program. Total funding for FY 1983-84: \$12,535.

OTEC plants will bring up cold deep ocean water, some of which may be expelled at the ocean surface after use. This nutrient-rich, relatively pure effluent has been shown to enhance the growth of a number of marine species that can serve as food sources. Studies are under way to link aquaculture facilities to OTEC plants. However, the effects on existing plant and animal communities in the area of the OTEC discharge must also be considered.

Phytoplankton are small floating plants that make up the base of the ocean food chain. Although nutrient concentrations of deep ocean water are many times those of surface water, other aspects of the composition of the deep water may affect the complete utilization of the major inorganic nutrients for phytoplankton production. This project undertakes a thorough ecological study of the effects of OTEC waste water on natural phytoplankton assemblages. Cold deep ocean water was used from the Natural Energy Laboratory of Hawaii at Ke-ahole Point on the Big Island.

Single species and natural populations were cultured in various mixtures of surface and deep ocean waters to evaluate their characteristics and growth rates. Similar cultures were also grown in deep water enriched with a complete mixture of trace metals, vitamins, and EDTA (ethylenediamine tetraacetic acid) a micronutrient mix, to assess the maximum yields attainable under macronutrient limitation. Cultures were allowed to grow until there were no further increases in total organic carbon; then they were harvested and analyzed for a number of factors.

Results showed that: (1) a lag time of growth response is about one week for natural assemblages of phytoplankton; (2) this lag time is reduced by 50% with the addition of the artificial chelating agent, EDTA; (3) maximum yields of phytoplankton population can be reasonably estimated with the quantity of limiting nutrient contained per chlorophyll *a*; (4) size distribution of phytoplankton population is greatly modified by the OTEC deep water; and (5) mostly large, pennate diatoms are enhanced and can be easily grazed by microzooplankton.

The project further identified problems for future study: (1) protein synthesis should be studied to understand physiological processes during the lag time; (2) bacterial contribution to chelation of heavy metals should be determined during the lag time; (3) grazing loss coefficient by microzooplankton should be examined; (4) settling velocity of enhanced phytoplankton cells should be determined; and (5) a model should be developed based on the information to be collected to describe phytoplankton bloom caused by the OTEC operation in Hawaiian water.



Dave Jones with Coulter counter used to determine concentrations and size distributions of natural phytoplankton

BREAKING WAVE FORCES ON OTEC PIPES

PRINCIPAL INVESTIGATOR: Robert A. Grace, Ph.D.
UHM Department of Civil Engineering

PROJECT STAFF: Eric K.S. Lee, Student Help
Erwyn C. Wong, Student Help

PROJECT PERIOD AND FUNDING SOURCE: The USDOE institutional grant provided funds of \$5,070 in early 1984 to resume this two-year-old project.

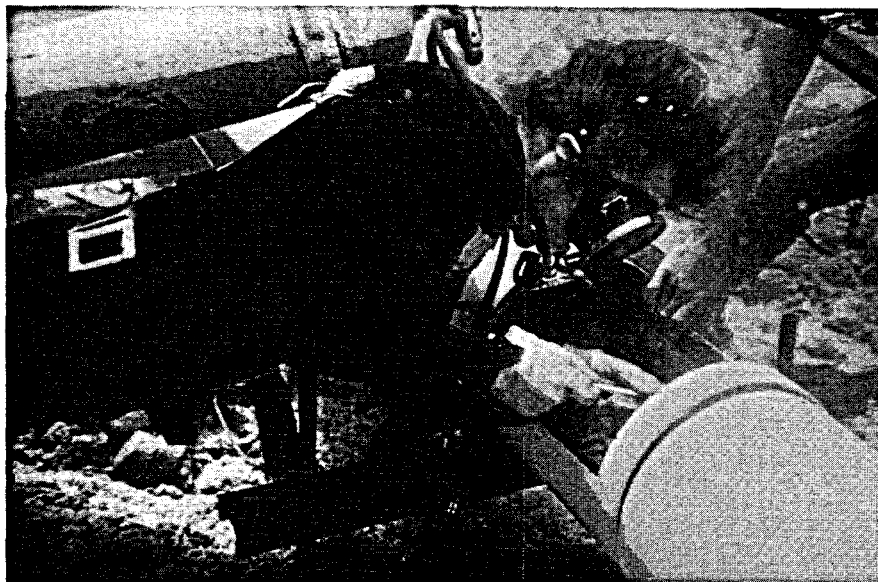
In shallow ocean depths, the main design consideration for OTEC cold water pipes involves the loads imposed by water motion under large waves. The 12-inch cold water pipe at the Natural Energy Laboratory of Hawaii (NELH) at Ke-ahole Point on the Big Island was designed with insufficient wave force information. Although the pipe itself has thus far not been harmed by large swells periodically impacting the area, the pipe support system has been damaged due to movement of the pipe and has needed repairs. The purpose of this study was to gather pertinent wave and wave force data useful in designing future pipes for Ke-ahole and elsewhere.

An ocean test site offshore of Honolulu and associated experimental apparatus were reactivated for this project. A special test pipe structure had been designed, fabricated, and installed at the site in 1982 to simulate the cold water OTEC pipe at NELH. The test pipe was at the same depth with approximately the same wave front-pipe angle (55°) as the NELH installation. Set up in 16 feet of water, the 12-inch diameter, 28-foot long test pipe was supported by special saddles fixed to the sea floor and had a central 4-foot section set up as a force sensor.

Some wave and wave force data were collected from the test rig during the first half of 1983. Wave heights to 7.5 feet were experienced. It was intended that this resumption of the earlier work would extend the results to substantially higher waves, and this was accomplished. Waves up to 12.4 feet high were measured and even higher waves were experienced. The peak horizontal load on the pipe force sensor was 120 pounds.

Although vertical loadings on the test pipe test section were measured, peak values of these correlate poorly with wave height. The correlation between wave height and maximum horizontal force on the pipe test section was very much better, but still by no means precise. A nonlinear least squares regression equation between wave height and peak horizontal force on the test section resulted in a standard error of estimate of 9 pounds for an average maximum force of 40 pounds. Flow history plays a major role in force variability, and *precise* force predictions appear impossible.

Data were successfully processed using various other techniques. One method was to plot maximum horizontal and vertical force coefficients against an adapted period parameter. Another method derived drag and inertia coefficients as functions of normalized water displacement.



Robert Grace attaches test section for tests of wave forces.

HYDRODYNAMIC LOADING ON SHELF-MOUNTED OTEC PLANT STRUCTURES

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

PROJECT STAFF: Martin J. Vitousek, Ph.D.
Joint Institute for Marine and Atmospheric Research
National Oceanic and Atmospheric Administration/UHM
Francis Benevides, M.S.
Federal Aviation Administration
Tarzen Su, Ph.D.
Jose Andres, M.S.
UHM Department of Ocean Engineering

PROJECT PERIOD AND FUNDING SOURCE: A continuation of a study funded for two years by state R&D support, this project was funded at \$12,983 for FY 1983-84.

Accurate prediction of hydrodynamic loading is essential to the design of slope-mounted cold water intake and discharge pipes for the planned 40 MW land-based OTEC plant at Kahe Point, Oahu, as well as for other shelf-mounted OTEC plants. The conventional single spectrum method of wave measurement tends to overdesign the structure. It is anticipated that a more realistic description of the wave environment through the use of omnidirectional wave spectra would result in significant cost savings, possibly 40 percent, in terms of pipe foundation requirements and associated deployment constraints.

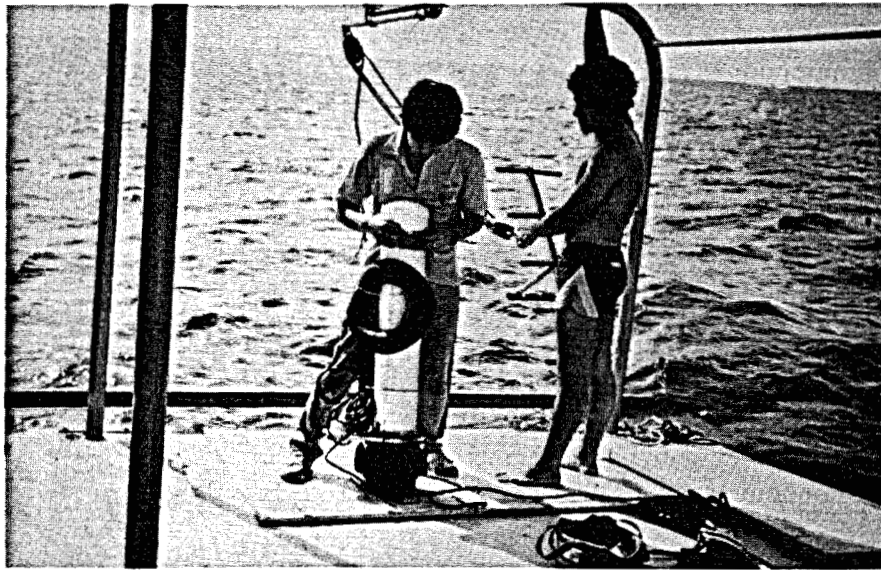
The major objectives of this project are:

1. To test and evaluate the directional wave spectrum measurement system as developed in the previous year of this project.
2. To determine the effects of nonlinearity, randomness, and directionality of waves on the hydrodynamic loading on a shelf-mounted OTEC plant, on a cold water pipe, as well as on the design requirements for foundations and deployment procedures.
3. To develop the analytical methodology leading to the most economical design of the OTEC platform and cold water pipe for the proposed 40 MW OTEC pilot plant.

The major accomplishment of the project was completion of significant modifications of the omnidirectional wave spectrum measurement system in order to reduce ocean bottom reflection of the sonic transducer system, and to increase the signal-to-noise ratio. Several at-sea tests of the system were made. Researchers hope the refined system will provide reliable omnidirectional wave spectrum information after further at-sea tests this summer.

The theoretical formulation leading to explanation of the kinematic and pressure wave fields at any depth in a nonlinear directional random sea has been obtained up to a second order. However, an efficient method to separate the free waves from the forced waves in the observed directional wave spectrum has not yet been established. Also, there is a certain degree of uncertainty about the uniqueness of the solution. Once this point is completely clarified, the theoretical model development will be completed.

To calibrate the model, the field data (ocean environment and wave force) at Ke-ahole Point were measured by the Hawaiian Dredging and Construction Company beginning in April 1984. The omnidirectional wave spectrum system will be deployed in the future. It should be noted that the project is behind schedule due to: (1) delay in modification of the omnidirectional wave spectrum measurement system; (2) delay in installation of the 8-foot diameter cold water pipe at Ke-ahole Point by the Hawaiian Dredging and Construction Company (from December 1983 to April 1984); and (3) illness of the principal investigator. However, efforts will be continued until the project objectives are met.



Tarzen Su (left) and Jose Andres conduct at-sea tests of the directional wave spectra system offshore of Ala Moana Beach, Oahu.



SOLAR ENERGY RESEARCH PROJECT SUMMARIES

Hawaii's most obvious energy resource is the sun. As the only fully tropical state in the union, Hawaii has global insolation rates that are among the best in the nation. Techniques to use this renewable, abundant, and clean fuel are numerous, of varying complexity, and currently in various developmental stages.

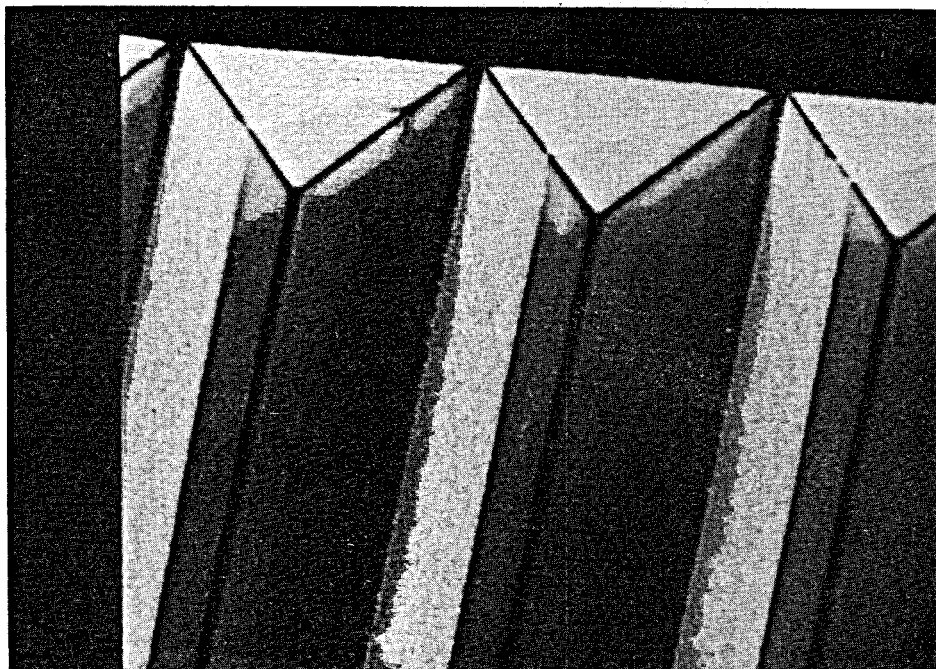
Passive solar systems, for example, involve the design of buildings to absorb or reflect sunlight to reduce energy costs for heating and cooling. Flat-plate collectors are fuel savers that use both diffuse and direct sunlight. These systems absorb heat which can then be transferred to hot water supplies or used for space heating. Solar ponds with layers of increasing salinity from top to bottom also trap the sun's heat in the saltier, heavier bottom layer; heat removed from this layer can be used for heat or generating electricity.

Other systems have been developed which concentrate the sunlight using mirrors, parabolic troughs, lenses, or dishes. These systems increase heat intensities from ten to as much as several hundred times and thus produce much higher temperatures than flat-plate collectors. Concentrating systems use only direct sunlight, and track the sun as it moves from east to west. The heat is used to produce steam or operate special engine-generators.

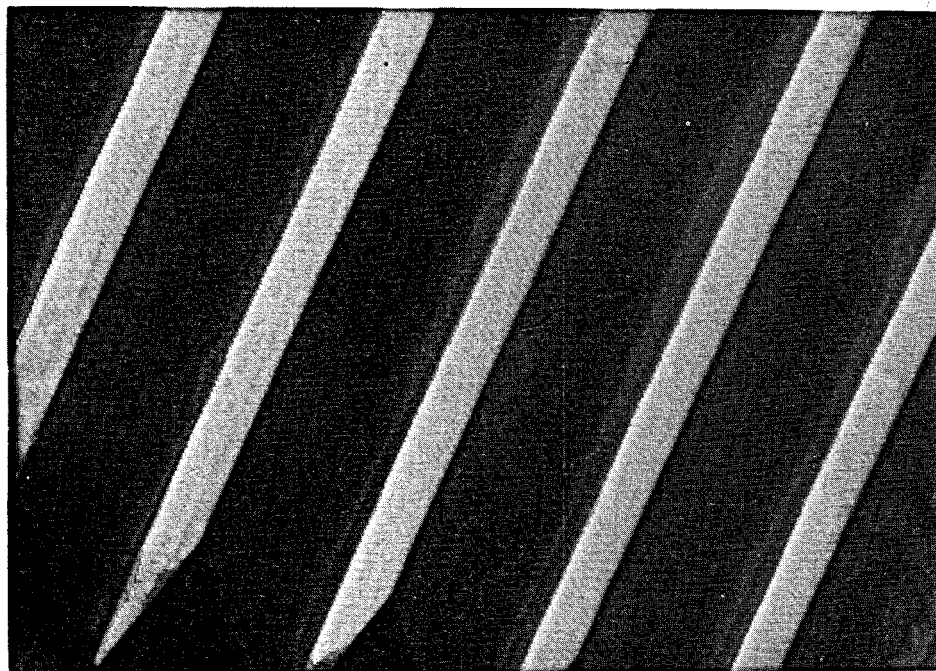
Electricity is the product of a photovoltaic (PV) cell. When photons of sunlight strike the cell, they free electrons which migrate to the contacts and produce a direct current of electricity. PV cells can be used in flat arrays or the production can be increased by placing them at the focal points of concentrating systems.

Prototypes, developmental models, and commercial systems of all these technologies are operating in the U.S. and most can be found in Hawaii. The county councils have developed building codes that support energy-efficient designs. Nearly 30,000 solar water heating units in the state give Hawaii the highest per capita rate in the U.S., and more than 250 photovoltaic systems on Kauai, Oahu, Hawaii, and Molokai are producing electricity and even hot water. Design of a 1-acre solar pond at the Natural Energy Laboratory of Hawaii is complete. Molokai is due to receive a 100-kW solar thermal system consisting of four parabolic dish collectors under a USDOE program.

Research continues, however, to collect solar data, solve technical problems, increase conversion efficiencies, develop specific applications for Hawaii, and reduce costs. HNEI is contributing to that research.



Enlarged view of a ridged grid solar cell. Metal contacts appear as light colored strips. Ridge peaks are 50 μm (microns) apart.



The silicon solar absorber. The front surface has been textured using ridged grid solar cell fabrication technology.

HIGH-TEMPERATURE SOLAR CONCENTRATOR ABSORBER FOR HYDROGEN AND WATER

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

PROJECT STAFF: Mark Lancaster, M.S.
Glenn Watanabe, B.S.
Richard Ida, B.S.
Physical Electronics Laboratory

PROJECT PERIOD AND FUNDING SOURCE: This is the fourth year of HNEI project funding; FY 1983-84 funds of \$8,706 came from the USDOE institutional grant. Various industries have donated equipment and devices.

Photovoltaics (PV) have received considerable attention in recent years because they are non-polluting, present no health hazard, and consume only the sun's energy. Because solar insolation is diffuse, photovoltaic arrays must cover a large area. Thus the cost of PV arrays remains high and not yet competitive with other energy sources except in special or remote locations. An alternative approach is to concentrate the sunlight from a large area onto a small-area photovoltaic cell. If the cost of the overall system is low, the cost per watt is low. The basic ingredients of the solar concentrator PV system are the concentrator, tracker, and PV cell.

Solar concentrator photovoltaics can provide dual power generation: the PV source as well as conversion of heat-rich waste energy. Earlier research developed a novel PV cell, the ridged grid solar cell (RGSC), which allowed for 100 percent absorption of concentrated solar radiation together with large current carrying capability. The present project concentrates on fabricating a cell to convert optical energy to thermal energy, and optimizing, characterizing, and testing the cell. This silicon solar thermal absorber cell can be used in thermochemical, electrochemical, and photoelectron assisted chemistry, specific applications of which include high-temperature hydrogen production. It can also be used in conjunction with a heat fluid and turbine generator to produce electricity.

The past year of this project concentrated on the experimental and theoretical development of the ridged silicon solar absorber, targeting operating temperatures as high as 1000°C. Temperature sensing and contact development leads to the use of a diffused resistor as an on-chip thermometer. Tests up to 600°C indicated that this is a suitable solution to temperature monitoring. Development of numerical techniques to provide the optical absorption and electron-hole generation rate throughout the device and the related thermal generation was completed. A heat transport numerical model continues in development.

Research on the ridged grid solar cell has continued in parallel with absorber development. It was found that a parasitic shunting resistance degrades solar cell performance. Experiments on the origin of the shunting resistance identified dislocations generated along the ridges during fabrication. An annealing process reduces the problem and will likely eliminate it.

SOLAR ENERGY LABORATORY ON THE ROOF OF HOLMES HALL

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

PROJECT STAFF: William Mok, M.S.E.
UHM Renewable Resources Research Laboratory

**PROJECT PERIOD AND
FUNDING SOURCE:** This project received USDOE institutional grant funding of
\$12,384 and state R&D funding of \$11,741 in FY 1983-84.

The solar energy laboratory on the roof of Holmes Hall was established in order to update the teaching curriculum to keep pace with the accelerating renewable energy research activities at the University of Hawaii and HNEI, and to share researchers' expertise and first-hand information on renewable energy technologies with graduate and undergraduate students. This facility supports both the educational and research activities of UHM, particularly those of the College of Engineering.

The objectives of this project are: (1) to set up course experiments designed to teach the fundamental principles of thermodynamics and heat transfer upon which solar energy conversion and utilization operate; (2) to demonstrate a variety of the latest solar technologies; and (3) to promote and facilitate the development of new independent research projects. In addition to completion of the basic laboratory facilities and equipment, such as a solar monitor and data recorders, a total of six experiments were set up. Experiments were designed to allow students to examine how classroom theories operate in practice and to provide them with hands-on experience with the latest solar devices and equipment. The solar energy laboratory has served a major role in one course, and further utilization in other courses is expected.

The experiments conducted were:

1. Solar Insolation. The experiments are designed to familiarize students with calibration procedures, relationships between direct, diffuse, and global insolation, and cosine error. Results of the experiments are compared with theoretical calculation or other published correlations.

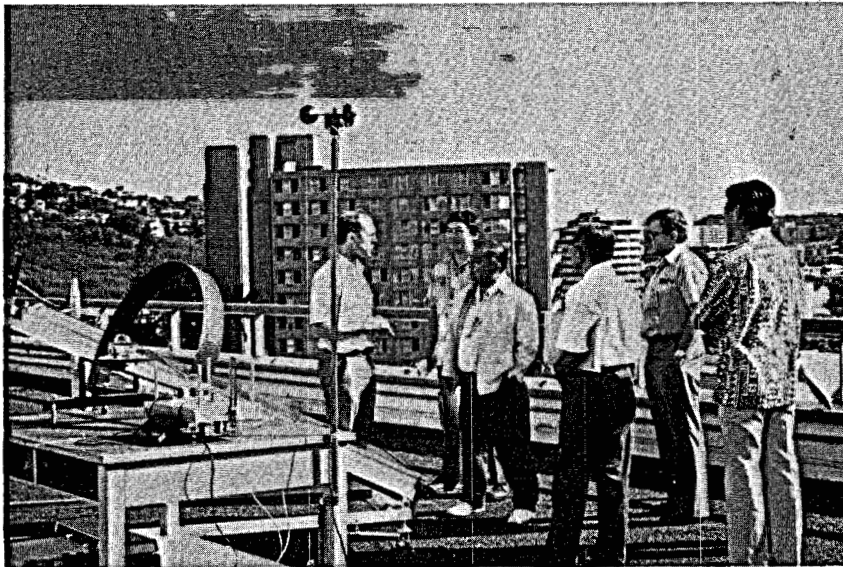
2. Solar Optics. This set-up can be used to measure the monochromatic biangular reflectance and monochromatic directional transmittance of a substance over a broad spectrum. Experiments are designed to illustrate the properties of a "selective" surface used as a collector receiver and to determine the desirability of various materials used as collector glazings.

3. Flat-Plate Collector. A common domestically used flat-plate collector fitted with special instrumentation proved to be a simple yet effective tool for the study of solar collector performance and heat transfer.

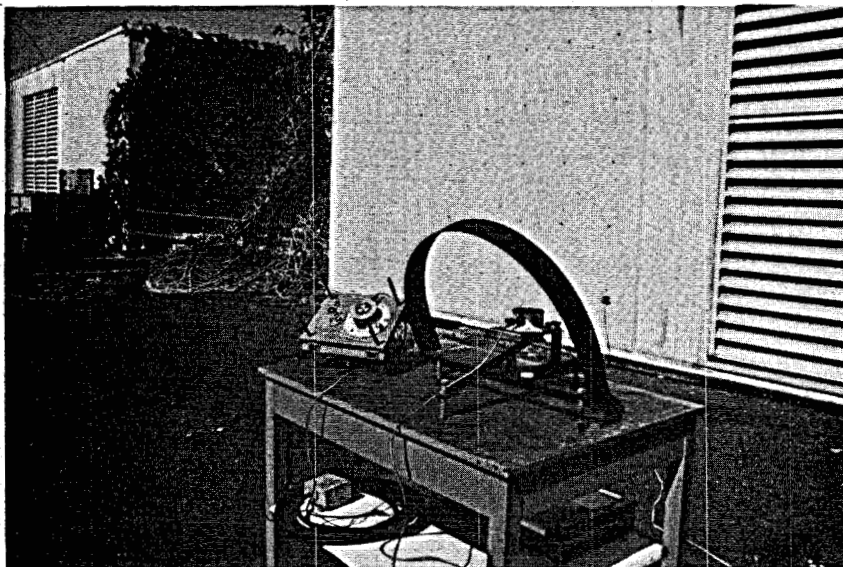
4. Parabolic Trough Collector. This experiment served more of a demonstrative purpose than as a tool for basic heat transfer studies because of the length of time it took to obtain efficiency data at various temperatures. However, students did benefit from the experience of operating this major type of concentrating collector.

5. Solar Cooling. A zeolite solar powered refrigerator, which utilizes the difference between day and night temperatures, serves as a demonstration of solar cooling and an illustration of the applications of fundamental thermodynamic principles.

6. Salt Gradient Pond. Solar salt gradient ponds collect and store energy for either space heating or power generation. A laboratory sized, well-instrumented unit was fabricated and will be used to study the effects of various operating parameters, such as salt gradient, depth, ground loss, coverings, and wind.



Michael Antal describes solar collectors and measurement devices to a group of visiting state senators.



Shadow band pyranometer, a device for measuring direct and indirect insolation.

CLEANSING TECHNIQUES FOR IMMISCIBLE SOLAR PONDS

PRINCIPAL INVESTIGATOR: Karl H. Bathen
UHM Department of Ocean Engineering

PROJECT STAFF: Robert Dollar, Student Help
Heidi Bathen, Student Help

PROJECT PERIOD AND FUNDING SOURCE: This continuing project received \$11,511 from the USDOE institutional grant in FY 1983-84. Research will continue pending state funds for building the prototype 1-acre solar pond at the Natural Energy Laboratory of Hawaii.

A solar pond is typically a shallow pond, a few meters deep, strongly stratified vertically with salt, ranging from 20 to 25 percent by weight in a black, absorptive, bottom storage zone and decreasing through a gradient zone to near zero at the surface. The salt-gradient zone gives the pond the unique characteristic that for most of its central depth it is nonconvective. The salinity has little effect per se on the energy collected or stored, but the central nonconvecting gradient zone stabilizes the pond against convective losses. This stability, allowing the pond to receive and store solar energy, makes it an effective and attractive solar energy converter. In tropical conditions a one-square-meter pond is capable in theory of producing up to 3 watts per cubic foot continuous output or 50,000 kilowatt-hours of usable power per year.

Four solar pond tests were completed in the previous project year to observe the ability of several immiscible fluids to absorb and store solar energy. The tests were conducted in two adjacent insulated laboratory ponds, each approximately one cubic yard in size. The change in the fluid characteristics, namely, spectral transmittance, vertical stability, biocide impact, and clarity, were examined following prolonged exposure to sunlight, wind, and the addition of ambient dust and debris. These tests were continued in the current work, while cleaning techniques were examined that would maintain pond clarity without disturbing pond stratification or causing a significant loss of heat.

Candidate fluids considered in the earlier work were selected based upon readily available materials vs. costs and the range of fluid properties they presented. Both convective and nonconvective, three-layered ponds were considered. In this project phase the emphasis was on determining the effect of cleansing on pond performance using two four-layered ponds of mineral oil, over water or salt water gradient, over a thin methylsalicylate and alcohol mix layer, over either glycerin or a 25 percent salt storage layer.

As in prior tests, the results indicated a more rapid warm-up behavior by the immiscible fluid pond over the comparative salt gradient mineral oil test pond. The salt storage pond, however, reached greater bottom temperatures. Glycerin bottom temperatures of 180°F and salt of 188°F were reached in 90 days and sustained for several subsequent weeks during cleansing tests. As before, a more rapid warm-rate was observed for the immiscible pond following mild disruption of the vertical stratification during cleansing. Despite attempts to limit the amount of debris reaching the test ponds, a wide range of material reached each pond surface daily. Cleansing tests were conducted weekly to insure pond clarity in addition to frequent injection of chlorine biocide. Temperature observations indicated the ponds reached 185°F to 192°F maximum bottom temperatures in 150 days.

Different optimum filtering methods were found for cleaning both the surface layer (i.e., just under the mineral oil surface layer) and the deep gradient and storage layers. The use of immiscible subsurface separation layers between the gradient and storage layers also indicates potential value in retaining pond stability and limiting debris penetration to the bottom storage layer in each case. Immiscible fluids—which dampen surface waves, aid in providing a fluid interface debris trap, and help to suppress mixing between pond layers—may prove useful to solar pond technology.



Karl Bathen prepares to take temperature readings from layers of solar pond.

HAWAIIAN SOLAR RADIATION MEASUREMENT AND DEVELOPMENT OF STATISTICAL PARAMETERS

PRINCIPAL INVESTIGATOR:

Paul C. Ekern, Ph.D.
UHM Department of Agronomy and Soils
Water Resources Research Center

PROJECT STAFF:

Stewart Chow, Student Help
Alyson Yim, Student Help
Blaine Akine, Student Help
Ryan Roback, Student Help

PROJECT PERIOD AND FUNDING SOURCE:

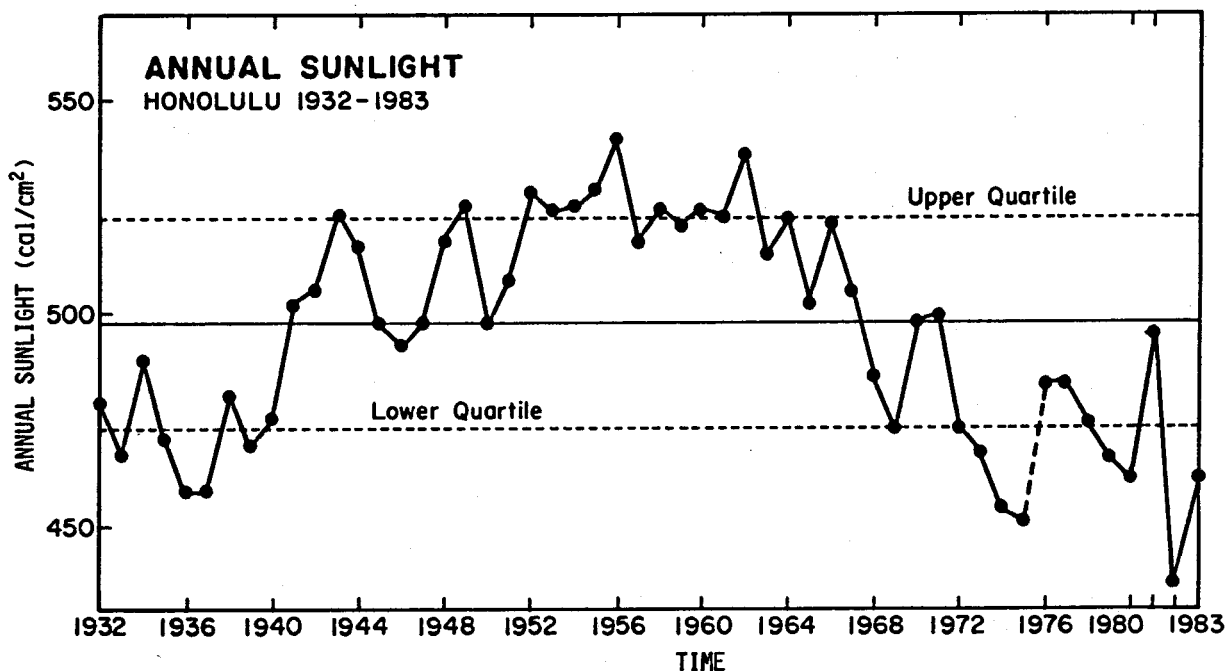
Support for this ongoing project came from state R&D funds which totaled \$5,802 for FY 1983-84.

Sunlight in one form or another is the source of almost all energy used today. This project measured the amount of sunlight and several statistical parameters of certain components of sunlight for key sites in Hawaii. The major objective was the extension of the record of sunlight begun in 1932 at Honolulu so that secular trends in sunlight might be detected. Global sunlight values in the Honolulu area have been in the lowest quartile for the last decade, and the annual value of 460.5 calories per square centimeter per day for 1983 continued that trend after recovery from the record low value during the El Niño of 1982-83.

There was internal consistency between the calibration by shading with the Eppley Normal Incidence and the Eppley Precision Spectral Pyranometer used as reference traceable through NOAA facilities at Boulder, Colorado, to international standards. Comparative calibration of other Eppley 848 and Licor sensors for global radiation used in Hawaiian networks had marked positive departures from the cosine response for low sun elevations for which adjustment must be made.

Direct beam normal incidence radiation averaged 0.9 the global value. Standard deviation of the noon hour direct beam averaged 40 percent, but ranged from 1 percent for clear hours to over 100 percent for partly cloudy periods. The ultraviolet portion approached 5 percent of the global sunlight throughout the year.

Direct recording of data on magnetic tape had limitations that make it essential to duplicate systems to ensure against data loss. Data reduced to engineering terms are available in table form, on disc, and on tape, for 15-minute, hourly, and daily intervals, and strip charts are available for shorter term assessment.



Annual insolation rates for Honolulu.

MEASURING AND DESCRIBING DIRECT INSOLATION ON MOLOKAI

PRINCIPAL INVESTIGATOR: George D. Curtis, B.S.
Hawaii Natural Energy Institute

PROJECT STAFF: Thomas A. Schroeder, Ph.D.
UHM Department of Meteorology
Paul Ekern, Ph.D.
Water Resources Research Center
Brian Ito, B.S.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: HNEI funded the initial phase of the project; Sandia National Laboratories funded subsequent phases at \$14,096 and \$3,766.

Measurement and characterization of direct insolation is vital to selection of suitable sites for concentrating solar systems, such as a parabolic dish project planned for Molokai, and prediction of their performance. However, for many areas, direct insolation values are less readily available than global data which are more easily measured and quite suitable for solar heating, agriculture, and other common uses. In addition, most data do not provide information on the character of the insolation needed by solar system designers.

A methodology was developed that uses a standard shadow band system with a data logger to provide much of the information needed. Numerical outputs are provided which include: global, diffuse, and calculated direct insolation; the standard deviation of the direct insolation; and, for each hour, the fraction of time the global insolation was above a preset level.

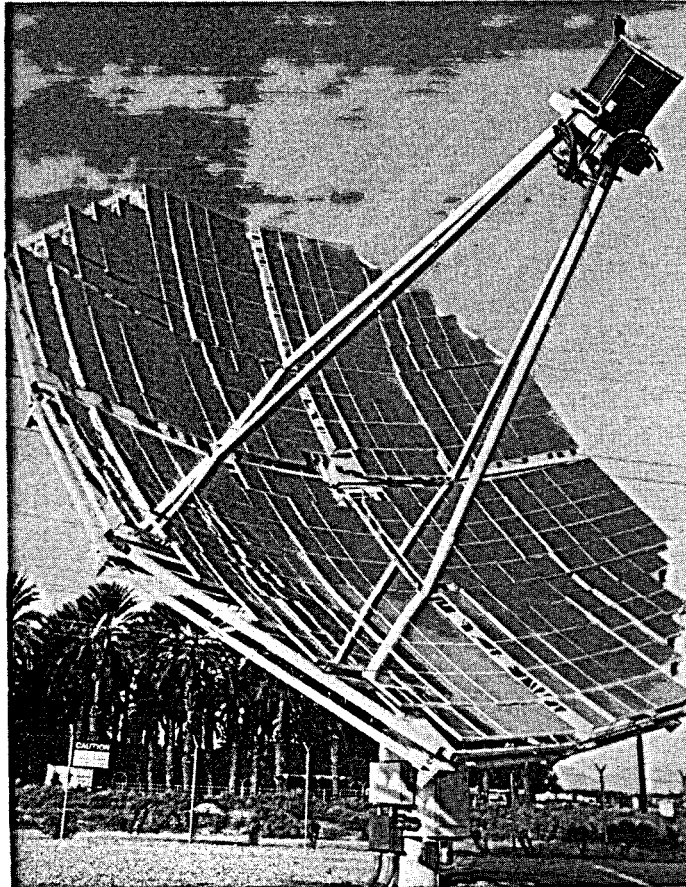
A Campbell Scientific CR-21 micrologger takes the data, which is recorded on tape, then played back in the laboratory and formatted with a desktop computer. The data gathering system was installed at a potential solar thermal site on the island of Molokai in 1983.

In early 1984 Sandia requested that HNEI use these and other available data to produce an estimated direct beam insolation map of Molokai. Data used to compose the Molokai map were: daily and annual global insolation data for a limited number of historical locations and hourly global data from three HNEI monitoring stations retrieved from in-house tapes; direct and global data from the UH Manoa base reference station and 50-year global data for the area; and rainfall and topography maps, wind charts, meteorological data, and satellite photos.

A general picture of the insolation with seasonal variations was formed from these data. For average and extreme periods, detailed data were retrieved and satellite photos set out. Estimates were made of ratios of direct to global insolation. With the addition of knowledge of winds and of cloud formation and movement, annualized numbers were derived for significant points and faired into lines of iso-insolation. Comparison with long-term data from UH was used to normalize the numbers.

The direct insolation map was produced along with explanatory notes on seasonal factors to aid in site evaluation. Subsequently, a contract was awarded by Sandia National Laboratories to provide computer-usable, direct insolation data for typical weeks at one site. These data were derived using a methodology similar to the U.S. government's solar/meteorological data gathering system.

A contract award is anticipated to add a second monitoring station, to provide better instruments, and to operate the stations for a year to aid in finalizing site selection, system design, and performance predictions.



Molokai insolation is measured in order to site a modular solar thermal electrical power generating system, which consists of one or more parabolic dish/heat engine units, like the one pictured. (Photo courtesy Advanco Inc.)

ROOFTOP PHOTOVOLTAIC SYSTEMS ON LIVED-IN UNITS IN HAWAII

PRINCIPAL INVESTIGATOR: Patrick K. Takahashi, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: Arthur Seki, M.S.
George Curtis, B.S.

PROJECT PERIOD AND FUNDING SOURCE: The USDOE through Sandia National Laboratories provided primary funding for this project of \$47,405 for fiscal year 1984. The total project cost over the four-year program was \$429,443.

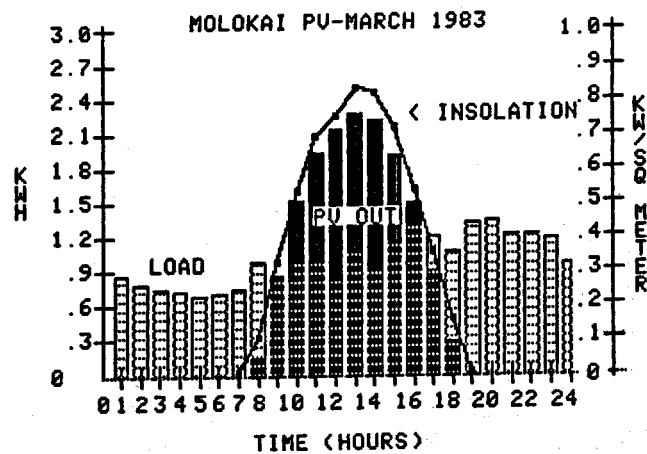
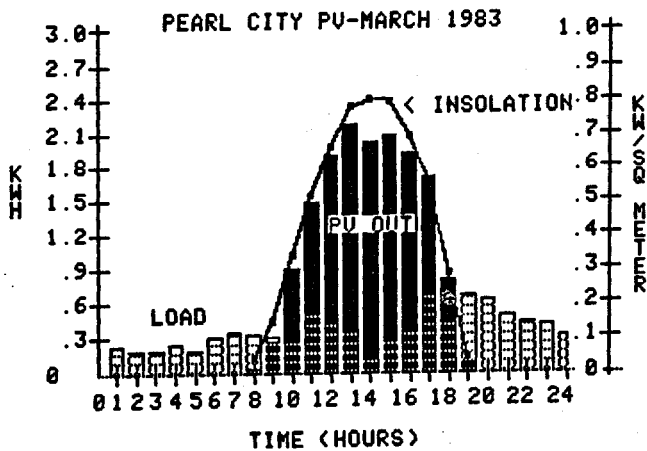
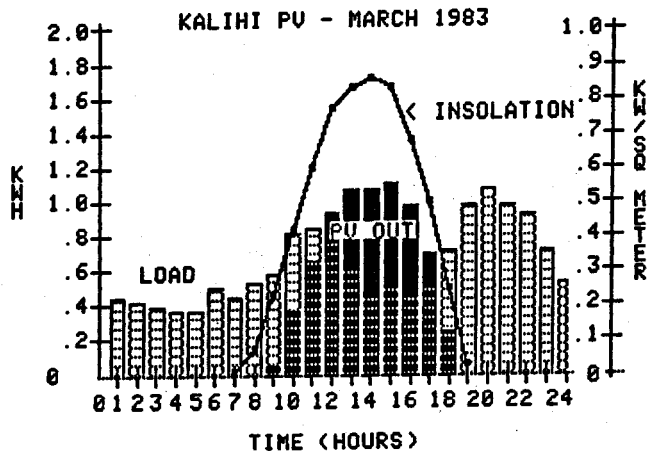
The overall goal of this project is to identify and resolve problems related to the operation and maintenance of three rooftop PV systems connected to the local utilities. The three homes selected for this demonstration represent different types of construction: a two-story duplex in Kalihi, which was part of an early redevelopment program; a two-story quadraplex in new public housing in Pearl City; and a 40-year old ranch home on Hawaiian homestead land on Molokai.

The PV systems were sized to approximate the annual energy requirements of the households: the Kalihi unit has a nominal 2 kW system, and the Pearl City and Molokai residences have nominal 4 kW systems and have solar water heaters to reduce electrical demand. The utility buys any excess energy produced by the PV systems and supplies energy to the residences when no PV power is being produced as there is no storage system.

HNEI is responsible for operation and maintenance of the systems, installing needed modifications, monitoring and evaluating the performance of the systems, and documenting and reporting this information. Information HNEI collects and records includes insolation, DC voltage, total array current, AC power voltage and power, subarray currents, array temperature, wind speed and direction, ambient temperature, and times of wetness. The data are collected with two Campbell Scientific CR-21 microloggers and stored on cassette tapes, which are then transferred to an HP-3000 computer for final data processing.

State-of-the-art inverters were installed at Kalihi and Pearl City because the utility was concerned with the poor quality energy provided by the Gemini inverter (i.e., lower power factor and waveform distortion). The new inverters have been trouble-free and have resulted in higher quality energy and 50 percent increased power factors. In addition, the wiring was modified at the Pearl City site to reduce the excessive amount of electricity exported to the utility by channeling the PV energy to all four units in the quadraplex. However, the benefits to the original single user have been reduced due to a change in utility billing procedure.

The PV systems have been operating satisfactorily throughout the period and have been on-line over 96 percent of the time. Problems were corrected quickly, and once the initial bugs were worked out, operational maintenance was routine. Performance has been as good as or better than expected. The Kalihi site operated at a lower than predicted level in 1982 but improved in 1983. Pearl City has been operating near expectations, and Molokai has outperformed the anticipated values. PV system performance results indicate that residents should make every effort to match their electrical usage to the PV energy production for optimum cost saving, since the utility buyback rate is about 50 percent of the residential cost of electricity.



Computer graphs of the load/PV profiles of the rooftop PV systems on lived-in units in Kalihi, Pearl City and Molokai.

PACIFIC ISLAND SOLAR MONITORING PROGRAM

PRINCIPAL INVESTIGATOR: Patrick K. Takahashi, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: Byron Auker, M.S.

PROJECT PERIOD AND FUNDING SOURCE: Initially funded by a one-year USDOE grant through the State Department of Planning and Economic Development, HNEI staffing continued this project a second year.

As a portion of a renewable energy assessment program for the U.S. Pacific Island Territories, global insolation data loggers were installed at American Samoa, the Marshall Islands, the Federated States of Micronesia, Palau, Guam, and the Northern Mariana Islands. This work was initiated by the U.S. Department of Energy and the State Department of Planning and Economic Development. HNEI's role in the project has been to receive data tapes and to write a computer program translating the hourly data into monthly tabulations. Funding was received for FY 1982-83 but was not renewed for the present year.

Although not currently funded, HNEI has continued to process data tapes as they are received. Most stations have ceased to function due to equipment problems; however, substantial data have been retrieved from American Samoa, Majuro, and Ponape. The most notable success has been the Saipan site, where 26 months of almost continuous data have been obtained.

The accompanying table gives a summary of monthly average insolation data received over the past two years. Hourly data is available from HNEI. For comparative purposes, global insolation data from Oahu is also included.

PACIFIC ISLAND INSOLATION

Monthly Global Insolation—Weighted Average
(kilowatt-hours/square meter/month)

Site	June-May 1982-1983	June-May 1983-1984	24 Month Average
SAIPAN	164 (96)*	169 (100)	167 (98)
AMERICAN SAMOA	134 (79)	134 (83)	134 (81)
MAJURO	170 (81)	151 (44)	163 (62)
PONAPE	154 (74)	113 (15)	147 (44)
TRUK	146 (37)	----	146 (18)
KOSRAE	136 (18)	----	136 (9)
PALAU	147 (17)	----	147 (8)
YAP	151 (6)	----	151 (3)
GUAM	----	----	----
OAHU, UH MANOA	158 (100)	168 (100)	163 (100)

* Parentheses show percent of data recovered.

PHOTOVOLTAIC POWER SYSTEM AT HAWAII INSTITUTE OF MARINE BIOLOGY

PRINCIPAL INVESTIGATOR: Patrick K. Takahashi, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: George Curtis, B.S.
Hawaii Natural Energy Institute
D. Richard Neill, B.S.
Hawaii Natural Energy Institute
Department of Planning and Economic Development

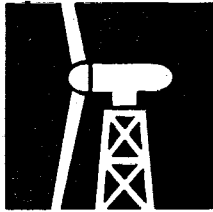
PROJECT PERIOD AND FUNDING SOURCE: HNEI provided service and equipment for this project in FY 1983-84 and Servco Pacific contributed \$3,000 worth of equipment. The total project cost, primarily from DPED amounted to \$72,000.

A photovoltaic (PV) demonstration project was installed on the rooftop of the Hawaii Institute of Marine Biology laboratory at Coconut Island, Oahu, in July 1984. It is now in operation and can produce up to 5 kilowatts of electrical power during peak sun periods.

The program was funded by the State Department of Planning and Economic Development in cooperation with HIMB and ARCO Solar. Installation was performed by Servco Pacific and SETS (Science, Education, Technology, Sales). HNEI has provided technical support and will monitor the operation of the system. In the last year HNEI: (1) reviewed the initial proposal from Millville Pacific (ARCO and SETS) and made recommendations regarding the design; (2) outlined the monitoring system and program to be used; and (3) provided sensors and transducers as part of the monitoring system and supervised their installation.

The PV system consists of 148 panels of silicon PV cells, each rated at 35 watts. A 1000 amp-hour, 48 volt DC lead-acid battery of 25 cells stores the extra energy produced at midday for use at other times. A 5 kW inverter converts the 48 VDC power from the PV cells and battery into 60 hz, 120 volt power similar to that supplied by the electric company. The system provides the electrical energy needed for the main office area of the HIMB facility.

The project will demonstrate the utility of a PV system in the island environment, and will provide data on possible future expansion to replace the stand-by diesels and submarine cable presently in use on Coconut Island. The monitoring system will aid in achieving this goal by showing the energy production relative to available sunlight (insolation), battery use, and surplus or shortfall of energy compared to the HIMB demand.



WIND ENERGY RESEARCH PROJECT SUMMARIES

HNEI continues to carry on a wind energy program with current emphases on maintaining key wind data stations of the Hawaii Wind Data Bank; research in the two critical areas of wind energy/utility interface and non-utility applications, including shifting the wind energy applications research center to Maui; and the public information, education, and technology transfer activities.

The long-term HNEI base reference stations have been reduced to Oahu's Kahuku 90-foot oceanside tower (with financial assistance from the Campbell Estate) and a 44-foot station at Opana; a 150-foot tower at Moomomi, Molokai; a 150-foot tower at the NIFTAL site on Maui, for which Maui Electric is now responsible, along with the Maui County Maalaea 150-foot tower; a 150-foot tower at Kahua Ranch on the Big Island (along with the ranch's 30-foot station); and the Waimea Airport 30-foot tower at Kamuela. These data stations along with the National Weather Service stations at Lihue, Honolulu, and the Kauai Electric Port Allen station currently make up the Hawaii Wind Data Bank statewide network. Daily average wind speeds are published in the HNEI *Wind Energy Technical Bulletin*. Frequent requests from the public, companies, and wind farm developers for more detailed data printouts are complied with when possible.

In addition to the wind energy battery storage (WEBS) program and the wind forecasting study, project summaries of which follow, research activities focused on developing ways in which utilities could successfully accept and use a greater input from wind energy. Preliminary work on a major program was carried on, with a proposal to be submitted in FY 1984-85 to USDOE for further funding. The second area of HNEI research interest is to develop ways that wind farm developers and landowners of prime wind areas could use wind energy independent of the utilities' demand. The main areas being investigated are: wind-powered water pumping, desalination by reverse osmosis; nitrogen and phosphorus fertilizer production; hydrogen generation; and battery charging for electric vehicles.

The HNEI *Wind Energy Technical Bulletin* reports statistics from the wind data bank and technology transfer ideas. The bulletin is mailed to more than 400 members of the wind community in Hawaii and beyond, providing information on wind energy conferences and activities, technological developments, possible problem areas and proposed solutions, and specific news on wind energy developments on the national level that affect Hawaii. Annual Wind Energy Technical Workshops were held in July 1983 and August 1984 with 80-90 people in attendance at each. The workshops were highlighted by field training and hands-on experience in wind gathering on Oahu, the Big Island, and Maui.

Papers were presented by HNEI staff at the International Solar Energy Society in Perth, Australia, the American Wind Energy Association annual conference in San Francisco, and the American Solar Energy Society meeting in Anaheim, California. Talks and slide presentations were given at a variety of other meetings and schools throughout the year. HNEI cooperated with DPED in presenting seminars on wind energy at Kamuela, Kahului, Kaunakakai, and Lihue. A second printing of the popular HNEI *Guidebook on Wind Energy Applications* was made, and an updated version is planned for 1985. HNEI staff provided assistance and information to several wind farm developers and landowners, loaned wind data accumulators, and provided information almost daily to callers on wind energy in Hawaii.

WIND ENERGY BATTERY STORAGE PROJECT

PRINCIPAL INVESTIGATOR: Patrick K. Takahashi, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF: D. Richard Neill, B.S.
Hawaii Natural Energy Institute
Department of Planning and Economic Development
George Curtis, B.S.
Byron Auker, M.S.
James Bac, B.B.A.
Hawaii Natural Energy Institute

PROJECT PERIOD AND FUNDING SOURCE: The past year of this continuing project was funded at \$67,358 by USDOE through Sandia National Laboratories, and \$21,899 from the state. Total funding for the project since 1981: \$321,880.

Electrical utilities are obligated to provide their customers with stable and reliable electrical energy upon demand utilizing complex, finely tuned generating systems that respond to rises and falls in demand, both immediate and long-term. The utilities understandably hesitate to allow more than 10 to 20 percent of their generating capacity to come from a variable and unpredictable source such as windpower.

HNEI's Wind Energy Battery Storage (WEBS) project is a research and development effort intended to provide energy storage to meet utility needs and ultimately to enable utilities to accept a much greater level of wind energy. The purpose of the three-phase WEBS project is to analyze, design, construct, and test a battery storage system involving interaction between batteries, wind energy conversion systems (WECS), and a utility system. The batteries would store excess energy that is intermittently produced by WECS or other generating systems, and distribute the power to the utility as needed to meet short or long-term demand.

A computer model was designed to evaluate the effects of energy storage on a utility system with a potentially significant portion of its generating capacity supplied by wind energy. The computer model used available data on WECS and battery systems, as well as extensive wind data that were collected at two locations on Molokai, Kalaupapa and Moomomi, as part of this phase of the project.

The computer simulation program originally modeled system performance considering variables in WECS, batteries, and utility load. This year the computer model was improved and expanded to include two-way interaction with the utility by taking utility operating characteristics into account. The utility generation system was modeled to determine how the utility matches its energy producing capability to user demand without wasting energy. A battery system was then designed that: (1) can save costs by using batteries rather than the more expensive components of the generating system, like diesel generators and (2) will reduce load fluctuations at the utility, thus maximizing the penetration level of windpower into the utility grid.

The computer program can produce the results of a selected one-year scenario in less than one minute. The outputs provide performance measures and annualized statistics for each WEBS configuration developed. Many scenarios were run on the model using actual data from Molokai's wind regime and Molokai Electric's generating systems and loads; however, the model can also be used for other utility configurations or adapted for much larger grids.

This research is intended to assist a utility in determining the spinning reserve it needs to compensate for fluctuations in wind energy input. The purpose was to explore the feasibility of forecasting the winds for time periods between one hour and one to two days.

The researchers' approach was to determine the characteristics of short-term fluctuations in Hawaiian winds, then attempt to identify the meteorological phenomena responsible for the observed fluctuations. Once the sources of variations were known, the feasibility of forecasting could be assessed and this assessment could help determine the organization of an operational forecast system to support wind farms.

The researchers analyzed long continuous data records from Kahuku Upper, a prime site for any Oahu wind farm, which has the most reliable long record of any of the Department of Meteorology or HNEI wind stations. Wind properties were considered and a Fourier analysis was run for two summer (July) and two winter (January) months. The Julys were similar but the Januarys represented extremes (2.5 mph average versus 19.1 mph average). In both Julys and the windy January (1979) the synoptic scale fluctuations (periods longer than two days) were the dominant features of the spectrum. The only month showing significant short-period fluctuations was that which had no significant winds (2.5 mph average).

Analysis of this data led to two conclusions:

1. The synoptic forecast is the most important concern for day-to-day wind farm operations because meteorological phenomena on the synoptic scale (i.e., the scale of the standard National Weather Service analysis and forecast effort) are the principal contributors to variance of even summer winds at Kahuku.

2. Short-period fluctuations are generally, but not always, insignificant. During periods of persistent trade winds the short-term fluctuations represent a very small portion of the spectrum. The dominant modes of trade fluctuations should be amenable to treatment by improved, specialized synoptic scale forecasting. In a separate program, Paul Haraguchi of Pacific Weather, Inc., has developed forecast tools based on synoptic data sources.

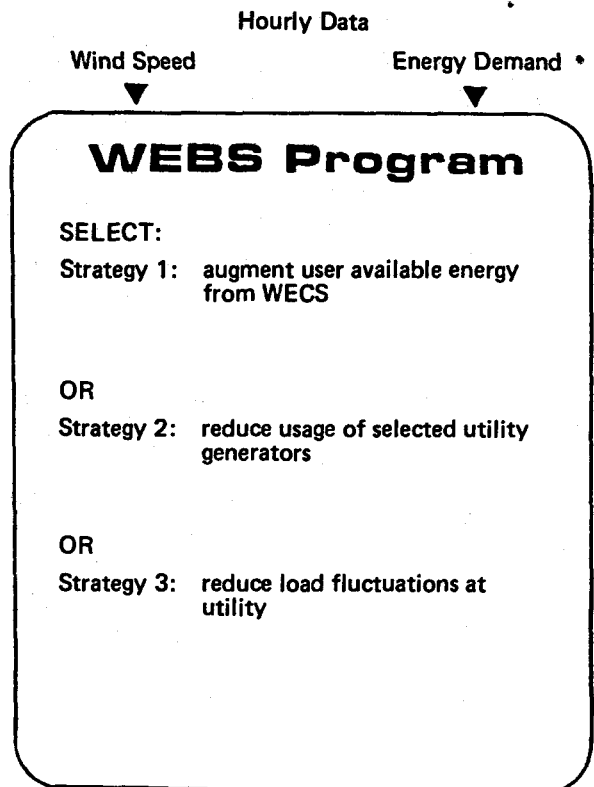
The present research suggests that the "intelligent wind farm" concept developed by George Curtis of HNEI be explored as the most promising means of wind farm response to short-term fluctuations. This approach is an extrapolation of the HNEI research on a wind-battery storage system. Outputs of selected WECS within the farm are monitored and integrated with a time constant to be determined. The integrated output is then examined for rate of change during a time to be determined, which could be extrapolated to a cut-out point. The wind farm would then communicate the information to the dispatcher controlling the grid, who would activate backup systems accordingly. Preliminary research could be performed within the next year using the Kahua Ranch wind farm as a test bed.

A battery storage facility, designed in Phase II with the aid of the computer model and in conjunction with a consultant, has been approved by Sandia.

Limited funding has been secured thus far for Phase III, construction of the battery storage facility. Although the State has released \$60,000 toward the project, the majority of funds must be sought from a combination of USDOE/Sandia, EPRI, the utilities, and wind farm developers.

PARAMETERS

- Batteries
 - number
 - capacity
 - discharge rate
 - charge rate
 - capacity at discharge
 - efficiency
- WECS*
 - power vs wind speed
 - cut-in
 - cut-out
 - number of machines
- Power Transmission
 - efficiencies
- Rectifier/Inverter
 - efficiencies
- Utility Parameters
 - strategy dependent



*Nine different machines presently selectable

Event Counts and Statistics for Battery Performance, WECS Performance, and Utility Performance

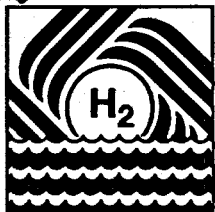
WEBS computer simulation

DEVELOPMENT OF A WIND FORECASTING PROGRAM FOR WIND FARMS

PRINCIPAL INVESTIGATORS: Thomas A. Schroeder, Ph.D.
 P. Anders Daniels, Ph.D.
 UHM Department of Meteorology

PROJECT PERIOD AND FUNDING SOURCE: This project was funded at \$4,535 for FY 1983-84 from state R&D funds.

The intermittent nature of the wind has concerned alternative energy developers since the first wind energy conversion systems (WECS) were built. Wind fluctuations pose two problems for a utility relying on wind as a component of the grid: (1) a "spinning reserve" must be available during lulls in the wind, however plans to use this reserve depend on reliable wind forecasting; and (2) turbulent fluctuations in the wind cause fluctuations in power output, which could adversely affect the quality of the power in the grid.



HYDROGEN RESEARCH PROJECT SUMMARIES

Hydrogen may be a "perfect fuel," but before it can compete with conventional fuels, more efficient and less expensive production, storage, and distribution methods must be developed. If these problems can be overcome, hydrogen may ultimately provide an answer to Hawaii's need for vehicular and jet fuel, which represents 60 percent of the state's energy use.

With potential reduction of the state's petroleum dependency in mind, Hawaii established a program to stimulate and coordinate hydrogen research efforts throughout the state, evaluate the potential for Hawaii to become an international research center for hydrogen production from renewable resources, and initiate information exchange and cooperative research efforts with the Asian Pacific and European communities. The first full year of the Hawaii Hydrogen Program was a very active one. The Hawaii State Legislature provided a \$50,000 appropriation to HNEI for R&D of hydrogen fuel. The funds were largely used to supplement support from USDOE for research projects at the University of Hawaii at Manoa.

Under this program, several researchers are investigating different aspects of hydrogen production through thermochemical conversion and photoelectrolytic methods. Funding from USDOE was also provided to a project by James Holm-Kennedy to develop a silicon solar absorber cell for high sun multiples (see Solar Projects). The cell can provide thermal, quantum, and electrolytic energy for the production of hydrogen and/or methanol.

Hydrogen storage is being investigated by several researchers. Hydrogen can be stored in hydrides at ambient temperatures and pressures, which makes storage easier, and with a density exceeding both liquid and gaseous hydrogen. Various transition metal compounds are being evaluated as possible storage media. Investigations include the chemical bonding between hydrogen and metal clusters, the properties of metal hydrides under ranges of temperatures and pressures, and laser studies indicating the amount of hydrogen certain metal hydrides can store. Mixtures of hydrogen and its isotope, deuterium, are also being examined under high pressures and temperatures.

In May 1984 HNEI organized the International Symposium on Hydrogen Produced from Renewable Energy, which brought together researchers, government program administrators, and industry representatives from around the world to share research information and initiate possible exchanges. Evolving from this symposium have been cooperative agreements for research and scholar exchange between Hawaii and Japan, Canada, and members of the European community. The symposium also resulted in Hawaii being considered as a future site for one of the biennial meetings of the International Association for Hydrogen Energy, with 1988 or 1990 considered as possibilities following the congress in Austria.

In other cooperative activity, HNEI and the Florida Solar Energy Center have collaborated on a proposal to USDOE, submitted in fall 1984, to support a major program for hydrogen production, storage, and applications research. Funds were provided in the USDOE budget by Congress.

At a planning meeting of the Pacific International Center for High Technology Research in Tokyo in April 1984, and at a follow-up workshop in August, energy storage, particularly hydrogen, was designated as a "high priority" research area. HNEI will work closely with PICHTR on this research effort.

The objective of the Hawaii Hydrogen Program to make Hawaii an international center for hydrogen research and development is off to a good start. We have captured the attention of the world, and now need to work closely with our partners to produce results.

ELECTRODE/ELECTROLYTE INTERFACES FOR HYDROGEN OR METHANOL PRODUCTION

PRINCIPAL INVESTIGATOR: William Pong, Ph.D.
UHM Department of Physics

PROJECT STAFF: Douglas E. Brandt, B.S.

PROJECT PERIOD AND FUNDING SOURCE: HNEI provided \$7,331 for this project from the state hydrogen grant in FY 1983-84. Application for continued funding is pending with SERI.

An important energy priority for Hawaii is to develop low-cost methods of producing hydrogen or methanol for fuel. A method of current interest is the use of solar energy to split water into hydrogen and oxygen with a semiconductor as an electrode catalyst. It is also possible to use this method to produce methanol from carbon dioxide and water. In either application, the incident optical energy is absorbed in the semiconductor electrode. If a suitable semiconductor is used, the photoexcited electrons can be injected into the electrolyte (water with H_3O^+ or CO_2) to produce the cathodic reduction reaction.

In order to develop a practical system for photoelectrolysis, it is important to know the photoelectric properties of the suitable semiconductor in contact with a given electrolyte. The objective of this project has been to determine the spectral photoresponse of p-type silicon carbide (SiC) in water. SiC is of interest because it may be particularly suitable for methanol production.

The photoresponse of p-type SiC of hexagonal structure was measured in the spectral region 2-5 eV using an n-type SiC crystal as a counter electrode. No external voltage was applied. The spectral yield expressed in number of photoinjected electrons per incident photon was found to be proportional to $(h\nu - \phi)^2$ for photon energies near the threshold ϕ of 2.1 ± 0.1 eV, where $h\nu$ is the photon energy. The yield increased more rapidly with photon energy above 3.3 eV.

The analysis of the yield data leads us to the following conclusions: (1) the threshold for photoinjecting electrons from the valence band of SiC into the acceptor states of water is approximately 2.1 eV; and (2) the optical transitions to the interface states are indirect and tunneling from the interface state is possible. The threshold value suggests that a significant part of the solar spectrum can be used for photoinjection of electrons from SiC into water. Further study in this area would be worthwhile. It would be interesting to see whether a threshold lower than 2.1 eV can be obtained with cubic SiC.



William Pong is studying the electrode-electrolyte interface between silicon carbide and water, which may be particularly suitable for methanol production.

CHARACTERIZATION OF HYDRIDES FOR HYDROGEN STORAGE

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

PROJECT STAFF: Brian Isa, B.S.

PROJECT PERIOD AND FUNDING SOURCE: This is the third year of HNEI support for this project; funds of \$5,227 came from the state hydrogen grant.

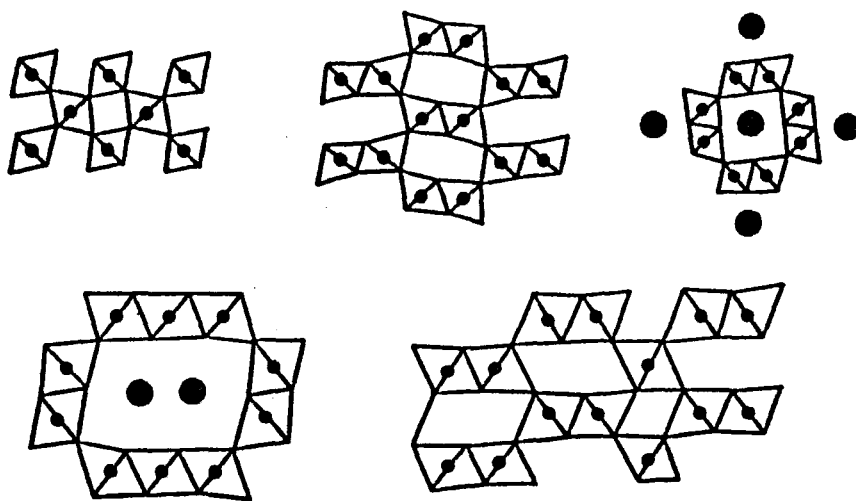
Storing hydrogen in solids known as hydrides offers advantages over storing it as a liquid or as a gas. Unlike gas storage, no heavy-walled pressure vessels are required; unlike liquid storage, there is no need to expend energy for liquefaction or use expensive insulated containers. However, inexpensive and effective materials for hydride storage need to be developed.

The objectives of this research were to identify novel materials for hydrogen storage that had not been considered previously and to apply the principles of materials science to narrow the choices to a few promising candidates. For example, it is well known that phase changes resulting in a structural rearrangement of the lattice increase the energy and hysteresis associated with the addition and removal of alkali metal atoms in solid-state cathodes. Similar effects are to be expected for hydrides. Also, structures containing tunnel or layered atomic arrangements have a greater potential for rapid atomic solid-state diffusion, necessary for rapid charging and discharging.

A number of transition metal compounds were investigated using recently developed transient electrochemical techniques to assess their suitability as solid-state materials for hydrogen storage. Novel materials considered for hydrogen storage were selected on the basis of their electronic properties and crystal structure; namely, a significant electronic conductivity and a lattice structure formed by octahedrally connected oxygen ions that form atomic-sized tunnels in one or more crystallographic directions.

Candidate hydride materials were evaluated electrochemically instead of by the traditional pressure vessel technique. Very precise control of the pressure was required to maintain stable cell potentials and allow both the compositional range and hydrogen diffusion coefficient to be obtained.

Diffusion coefficients of the order of 10^{-4} cm²/sec were measured in some of the hydrides at room temperature and low hydrogen concentrations. The structurally attractive manganese oxides had significantly lower hydrogen solubilities and diffusion coefficients than the more traditional materials such as the lanthanum-nickel-aluminum and iron-titanium hydrides.



Manganese oxides form a wide range of crystalline structures; however, they do not fare as well as the more traditional hydrides in storing hydrogen.

CHARACTERIZATION OF METAL HYDRIDES SUITABLE FOR HYDROGEN STORAGE OR METHANOL-HYDROGEN CONVERSION

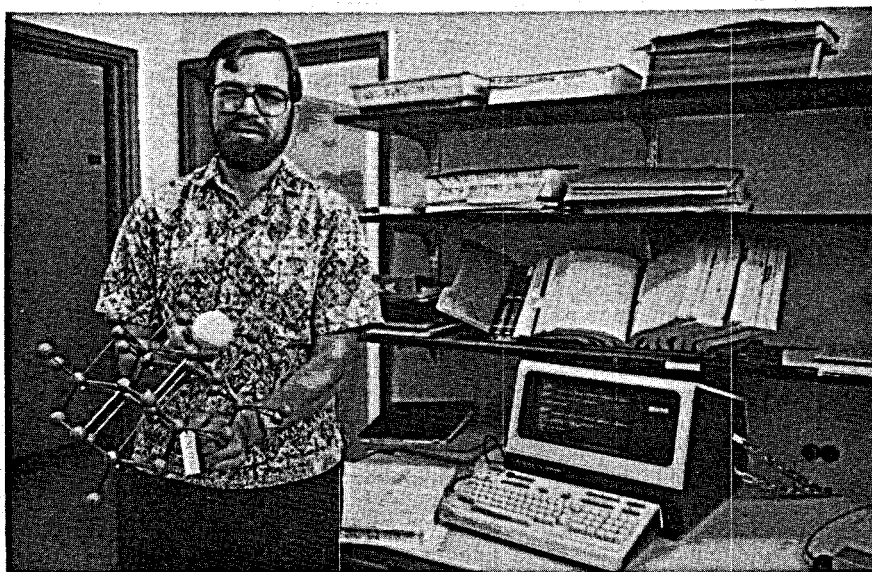
PRINCIPAL INVESTIGATOR: Philip W. Payne, Ph.D.
UHM Department of Chemistry

PROJECT STAFF: Hyunsook Kim, Student Help
Layton Tanaka, Student Help
Mason Yamashita, Student Help

PROJECT PERIOD AND FUNDING SOURCE: Funding of \$5,635 from the state hydrogen grant was supplemented by \$5,000 from the UHM Faculty Revolving Fund. This project ran from September 1983 through June 1984.

Certain metals and their alloys can absorb and store hydrogen gas in the form of compounds called hydrides. An improved understanding of the chemical bonding between hydrogen and these metals or alloys will help to determine which ones can store the most hydrogen per weight while degrading the least. Study of the physical chemistry of these metal hydrides is critical not only for reversible hydrogen storage, but also for the design of novel materials for electrolytic hydrogen generation and catalytic conversion of hydrogen to alternative fuels such as methanol.

This project has developed accurate quantum mechanical methods to simulate electronic structures, chemical bond energies, and local vibrational modes of transition metal clusters and their hydrides. These computational tools provide an interpretative framework for electronic and vibrational spectroscopy of electrodes or hydrogen bearing alloys, and will clarify the binding sites, thermodynamic properties, and reaction pathways of hydrogen in metals.



Philip Payne shows a three-dimensional model of how hydrogen (large white sphere) is stored within the structure of a transition metal cluster. He uses the computer terminal to perform quantum mechanical calculations clarifying this bonding of hydrogen to metals.

Investigators have formulated a compact theory of electron correlation that may be especially suitable for transition metal clusters, in which numerous electronic states have comparable energy. Electron correlation takes into account the instantaneous coulomb repulsion between electrons of each pair. A correct treatment of correlation effects is necessary for accurate prediction of bond lengths, bond energies, or vibrational frequencies for transition metal species. Standard computational techniques to study electron correlation, reported elsewhere in the scientific literature, quickly become unwieldy for transition metal clusters and are often inaccurate. Thus, the accomplishments of this project constitute a fundamental advance in understanding the electronic structure of transition metal clusters.

Elaborate computer programs are being constructed to test the model of electron correlation in transition metal clusters and their hydrides. To facilitate such calculations, the researchers have also considered pseudopotential techniques, which treat the coulomb repulsion of valence and core electrons in an approximate way. Pseudopotentials can reduce computational labor by two orders of magnitude. Numerical tests showed that pseudopotentials based on a Padé approximate representation of atomic orbitals are inadequate. But concurrent development of transition metal pseudopotentials by other investigators makes further work on that topic unnecessary.

Future work will focus on prediction of vibrational modes for interstitial hydrogen in transition metal clusters. These vibrations are detected by neutron scattering experiments performed at various federal installations, and collaborative relationships with those institutions are being developed.

INTERACTION OF HYDROGEN AND DEUTERIUM WITH TRANSITION METALS AND THEIR ALLOYS AT HIGH PRESSURES

PRINCIPAL INVESTIGATOR:

Shiv K. Sharma, Ph.D.
Hawaii Institute of Geophysics

PROJECT STAFF:

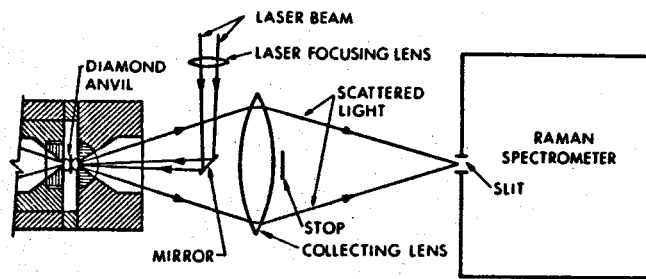
James K.L. Lau, B.S.
UHM Department of Chemistry
David W.B. Au, B.S.
UHM Department of Mechanical Engineering

PROJECT PERIOD AND FUNDING SOURCES:

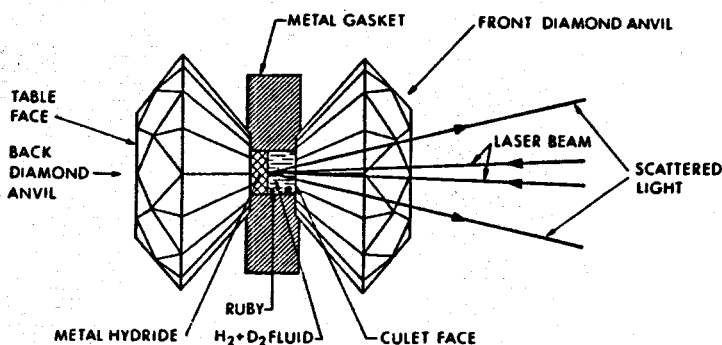
The second year of this project was funded by the USDOE institutional grant at \$8,861 and the state hydrogen grant at \$8,117, with additional state and USDOE funds of \$6,000 for purchase of an improved laser system. A proposal to the National Science Foundation to continue this work is pending. Total FY 1983-84 funding: \$22,412.

Metal hydrides (MH_x) are important metal-hydrogen compounds for storing large quantities of hydrogen gas safely in a relatively small space. The amount of hydrogen stored in transition metals and their alloys can be increased if the hydrogen gas is loaded into these materials at elevated pressures. The objectives of this research project are, first, to acquire and develop an advanced high-pressure diamond anvil cell (DAC) system capable of operating at cryogenic temperatures. Liquid

Schematic for Raman scattering studies with the low-temperature diamond anvil cell in the 180° scattering geometry.



Detail of the optical rays through the diamond anvil and the gasket hole in backscattering geometry.

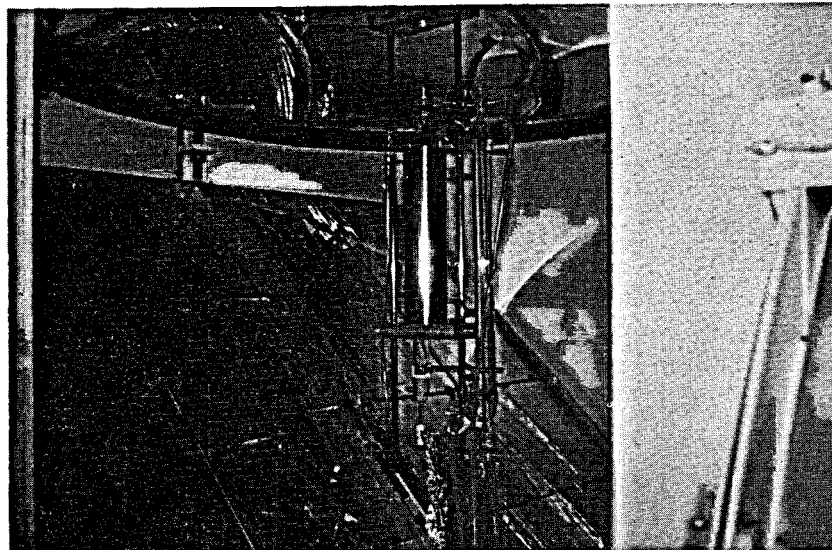
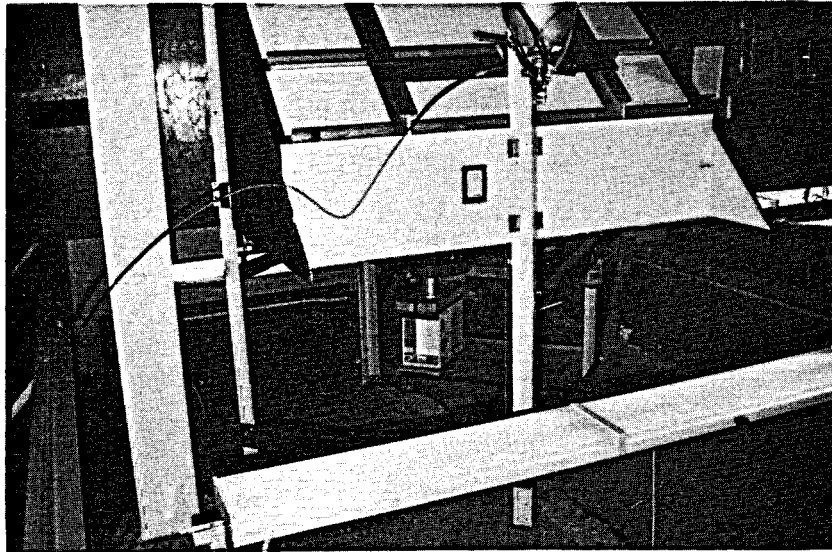


hydrogen (H_2) and deuterium (D_2) mixtures would be loaded with the metal samples in the low-temperature DAC to investigate pressure and temperature conditions at which various metals and alloys have the optimum capacity for storing hydrogen in the solid phase. The second objective is to develop experimental techniques, such as laser-Raman spectroscopy and x-ray diffraction, for *in situ* studies in the DAC of the interaction of fluid hydrogen with metals at high pressures (0.5–100 kbar) and high temperatures (25–300°C) (see figure).

During this grant period a new liquid helium cryostat was acquired and the loading system was modified to improve the loading of liquid mixtures of H_2 and D_2 in the DAC. An optical system efficiently coupling the DAC with an existing laser-Raman spectrometer in 180° scattering geometry has been developed. Laser-Raman spectroscopy is being used for studying rates of reaction of H_2 and D_2 at various metal surfaces. The H_2 , D_2 , and HD molecules present in the fluid phase produce distinct bands in the Raman spectrum. Information on the rate of reaction at various metal surfaces can be obtained by monitoring the rate of formation of HD molecules in the fluid phase. Two cameras were fabricated for *in situ* high-pressure x-ray diffraction studies of metal hydrides in the low-temperature DAC.

HNEI provided matching funds for acquiring and developing a basic ^{57}Fe Mössbauer spectrometer and for purchasing a Nd:YAG pulse laser system for laser-Raman spectroscopic studies of metal-hydrogen systems in the DAC. The Mössbauer measurements at high hydrogen pressures are expected to yield information about metal-hydrogen interactions at the metal surface as well as in the bulk material.

With the development of the high-pressure Mössbauer and laser-Raman spectroscopy and x-ray diffraction techniques, the University of Hawaii now has a unique high-pressure facility for *in situ* investigation of the interaction of fluid H_2 and D_2 with metals and alloys. This facility will provide an understanding and resolution of the general problems associated with hydrogen storage and, more particularly, will help to evaluate the usefulness of hydrogen in the form of metal hydrides as an energy resource.



The fast thermogravimetric analyzer (TGA) system is used to study high temperature, solid phase decomposition using concentrated radiant energy from the solar arc image furnace. The TGA system is shown at the base of the arc image furnace (top photo) and at the focus of the arc image furnace (lower photo).

THERMAL DECOMPOSITION OF ZINC SULFATE RELATED TO SOLAR-THERMOCHEMICAL HYDROGEN PRODUCTION

PRINCIPAL INVESTIGATORS: Michael J. Antal, Jr., Ph.D.
UHM/HNEI Coral Industries Professor of Renewable Energy Resources
Ali Tabatabaie-Raissi, Ph.D.
UHM Renewable Resources Research Laboratory

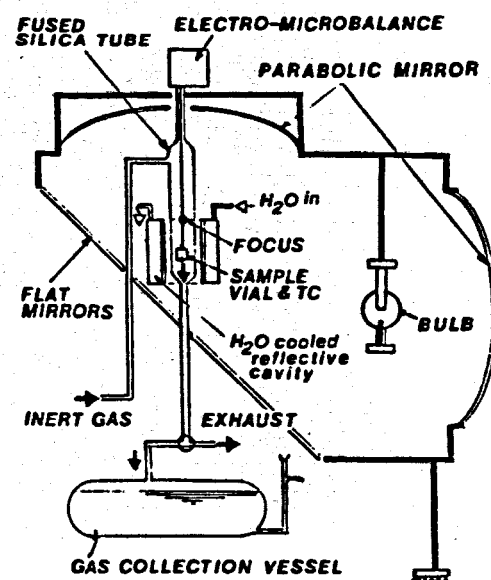
PROJECT PERIOD AND FUNDING SOURCE: Initial HNEI seed money of \$4,254 for FY 1983-84 from the state hydrogen grant was instrumental in beginning this research and in obtaining funds of \$85,131 from USDOE to continue this project.

One of the most promising long-term chemical applications of concentrated solar thermal energy is direct, solid phase decomposition of zinc sulfate ($ZnSO_4$). Thermal decomposition of $ZnSO_4$ is applicable to thermochemical hydrogen production via water splitting cycles either as a main process step or as a subcycle to replace the concentration and decomposition of sulfuric acid. The formation and decomposition of sulfuric acid constitute the major steps involved in many advanced hydrogen production cycles.

On the other hand, the mechanisms of hydrous $ZnSO_4$ decomposition have been a point of controversy, especially at very high sample heating rates. This is reflected in the inconsistencies in reported values for initial decomposition temperatures of hydrous zinc sulfates.

This project initiated an exploratory study of the kinetics and mechanism of zinc sulfate decomposition at low and high heating rates. As a result of this preliminary investigation, a major research program was funded by USDOE to continue the research with the primary objective of accomplishing a fundamental study of high temperature, solid phase decomposition at high heating rates using concentrated radiant energy from an arc image furnace. The goal of the ongoing research is to develop an apparatus capable of rapidly weighing materials within a concentrated radiant flux environment. More conventional low heating rate experiments were conducted with a newly acquired Setaram thermogravimetric analyzer/differential thermal analyzer (TGA/DTA). The results of low and high heating rate experiments are to be analyzed using recently developed, sophisticated mathematical models. It is of interest to learn whether data derived from low heating rate studies can be extrapolated to high heating rates to infer solid phase decomposition chemistry effected by concentrated radiant energy.

The Mark I fast thermogravimetric system has been fabricated and is currently being used to compile data for high heating rate thermochemical conversion of solid materials. The low heating rate studies also continue and the data is being analyzed.



Schematic of the fast thermogravimetric system.

CHARACTERIZATION OF METAL HYDRIDES AT HIGH PRESSURES AND TEMPERATURES

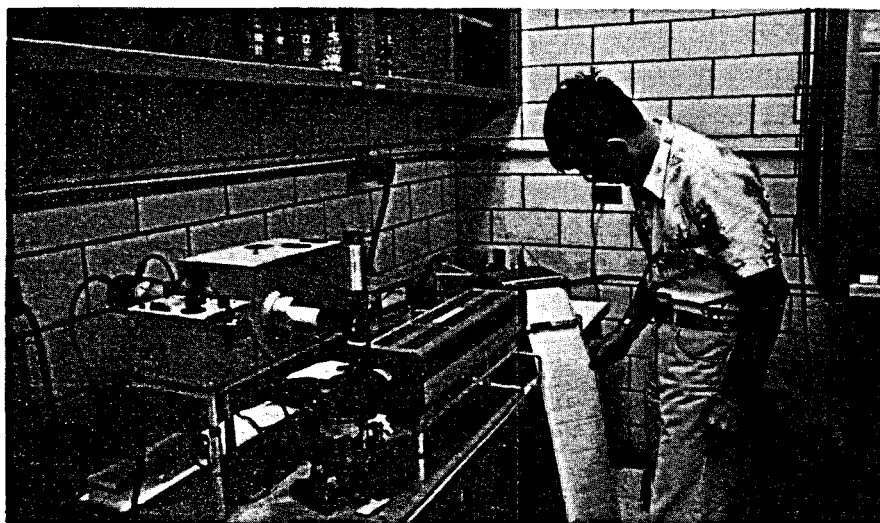
PRINCIPAL INVESTIGATOR: Li-Chung Ming, Ph.D.
Hawaii Institute of Geophysics

PROJECT PERIOD AND FUNDING SOURCE: HNEI assisted this project in FY 1983-84 with \$3,850 from state hydrogen grant funds.

Hydrogen's great promise as a substitute for gasoline fuel used in future ground and air transportation makes the problem of storing hydrogen safely and compactly a major concern. Metal hydrides with relatively high percentages of hydrogen per unit volume are a potential solution to the problem. For the proper use of metal hydrides as energy carriers in various applications, it is of paramount importance to understand more fully their physical, chemical, and crystallographic properties under wide ranges of pressure and temperature conditions.

The objectives of this research are to utilize recent advancement in high pressure-high temperature technology (i.e., the diamond anvil cell) and x-ray diffraction techniques to synthesize denser hydrides, to investigate the stability region in the pressure-temperature space, and to determine pressure-volume relationship at constant temperature for various metal hydrides. Results of this research project have both basic and applied aspects in science and technology related to hydrogen storage.

This project investigated polycrystalline titanium hydride (TiH_2) and palladium hydride (Pd_2H) under static pressures up to 20 GPa (200,000 atmospheres) and at room temperature using a diamond anvil cell. The pressure of the sample was determined either by gold as an internal standard or by the well-established ruby fluorescence method. The crystal structure and the molar volume of the sample were determined by means of an x-ray diffraction technique with a high intensity x-ray source (i.e., in-house 12 kW rotating anode x-ray generator or synchrotron radiation from Stanford Synchrotron Radiation Laboratory). Preliminary *in situ* x-ray diffraction data from TiH_2 show that TiH_2 with face-centered cubic crystal structure is stable up to 20 GPa at room temperature and the molar volume change at 20 GPa is approximately 8 percent. Studies on Pd_2H and other metal hydrides are in progress.



Li-Chung Ming examines readout from the optical system of the ruby fluorescence for determining the sample pressure in the diamond anvil pressure cell.



OTHER RENEWABLE ENERGY RESEARCH PROJECT SUMMARIES

This category of renewable energy research covers two types of projects: those that by their nature cut across the major technologies discussed in the previous sections and others in emerging areas of research that could become major programs in the future.

All renewable energy developments will have an impact on the environment; because these technologies are new, all these impacts cannot be predicted. Therefore, it is necessary to make careful baseline environmental assessments and to continue with follow-up monitoring throughout the installation and operation of wind farms, geothermal or OTEC power plants, or biomass conversion facilities. Environmental monitoring at HGP-A has been a continuous process since before the well was drilled. Hydrogen sulfide and mercury levels and their effects on humans and the environment have been a major concern.

The Hawaii Deep Water Electrical Transmission Cable Demonstration Program is a massive effort to link the energy sources on the Big Island to the energy market on Oahu. HNEI is playing a part in that effort by performing corrosion, abrasion, and biofouling studies of potential cable materials. Such materials studies may also have relevance to OTEC and other renewable energy systems.

The four-year USDOE electric vehicle project has been extended. Solutions to the problems of the early EVs, along with other advances, may make EVs commercially feasible in the future. The EV program has provided a stimulus for HNEI to form a new alternative transportation program. Discussions are under way regarding the aluminum-air battery, roadway powered EVs, and flywheel-driven public transportation. Linked closely with liquid fuels research being carried on in HNEI's biomass research program, transportation alternatives will be a major area of research effort for the next decade.

ELECTRIC VEHICLE PROJECT

PRINCIPAL INVESTIGATOR:

Patrick K. Takahashi, Ph.D.
Hawaii Natural Energy Institute

PROJECT STAFF:

D. Richard Neill, B.S.
Hawaii Natural Energy Institute
Department of Planning and Economic Development
Frank Matsumoto
UH Transportation Services
James Bac, B.B.A.
Hawaii Natural Energy Institute
Kevin Funasaki, Student Help
UH Transportation Services

PROJECT PERIOD AND FUNDING SOURCE:

This project was initiated in 1979 and is jointly funded by USDOE and the state. Total funding in FY 1983-84: \$14,847. The EV improvement program was granted \$30,000 for FY 1984-85 by USDOE. The program has received \$452,962 since May 1979.

The goals of the EV Project during FY 1983-84 were:

1. To improve upon the monthly mileage record of the University's EV fleet of sedans, pick-up trucks, and vans;
2. To subsequently increase the use of each EV by providing the necessary support to maintain the vehicles in a satisfactory operating condition, together with obtaining technological improvements to enhance maintenance;
3. To initiate an improvement program to upgrade the driveability, reliability, and operational performance of the University's EV fleet; and
4. To inform the public about EVs and promote their value as an area of energy research.

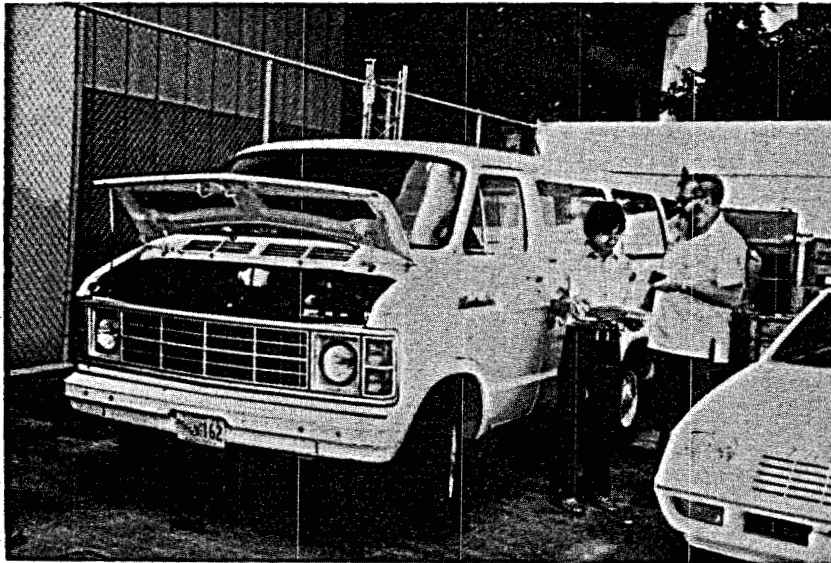
During the course of the year, limited resources led to the eventual reduction of the EV fleet from fifteen to nine vehicles. With this smaller fleet, however, more efficient and effective use of personnel, time, and funds was possible. On the average, seven EVs were in operation each month and for the year recorded an average of 124 miles per month per operational EV. Further improvement in the monthly mileage record of the University EV fleet will be sought as HNEI continues its efforts under the USDOE Product Improvement Program.

To enhance and support EV maintenance, HNEI has been closely monitoring operator experience in a related USDOE Product Improvement Test and Evaluation Program. HNEI has also received an additional \$30,000 from USDOE through participation in an EV improvement program. The grant will be used to improve several EVs and acquire support equipment such as a "water wand" to reduce the time spent for battery watering maintenance.

HNEI has also acquired technological improvements to upgrade the performance of drivers and vehicles in the University's EV fleet. Subsequently, HNEI has purchased a cableform controller, three PMC transistorized controllers, voltmeters to assist drivers in monitoring vehicle performance,

bellville washers to reduce problems from terminal meltdown, batteries with tapered battery posts for better terminal connection, and arc welding battery cables for more reliable battery interconnection.

Efforts have also been made during the year to inform both special interest groups and the general public about electric vehicles. This has been done through: (1) sponsoring an EV Training Session and Follow-up workshop September 16-17, 1983, for participants in all Hawaii public and private EV programs to form a network for problem-solving and spare parts exchange; (2) publication of *Hawaii EV News* (January and April 1984); (3) reassignment of an EV to the Department of Planning and Economic Development, State of Hawaii; (4) staging an EV Driver Training/Sharing Session on May 4, 1984 for expert and new EV drivers; and (5) giving slide and demonstration presentations about electric vehicles at schools. For the future, HNEI plans to actively participate in the USDOE Product Improvement Program, to reach a higher plateau of its basic goals, and to continue sponsorship of workshops to transfer EV technology from specialists to community users.



HNEI's Jim Bac (left) and Dick Neill check the Electra Van 1400, which is being converted in the EV modernization program.

ENVIRONMENTAL QUALITY STUDIES

PRINCIPAL INVESTIGATORS: Sanford M. Siegel, Ph.D.
UHM Department of Botany
Barbara Z. Siegel, Ph.D.
Pacific Biomedical Research Center

PROJECT STAFF: Cheran Wilson, B.S.
UHM Department of Botany
Elizabeth Yaeger, Student Research Trainee
Michael Lasconia, Student Research Trainee
Pacific Biomedical Research Center

PROJECT PERIOD AND FUNDING SOURCE: These continuing studies received \$10,631 from HNEI state R&D project funds during FY 1983-84, with matching funds of \$12,000 granted by HECO for the Rotorua study. The Rotorua study will be continued in FY 1984-85 with \$13,000 from HECO.

The Environmental Quality Studies project is the continuation of work begun at HGP-A in 1975. Its purpose is assessment of baselines and environmental changes related to the development of renewable energy resources, especially geothermal, in volcanic areas. The two geothermal/volcanic emissions of special concern are mercury and hydrogen sulfide.

Monitoring of mercury at HGP-A and its environs has been combined with mapping of air, soil, and ohia (a native tree) mercury distribution. A report completing the seven-year (1975-82) distributional study in Puna was submitted to HNEI in October 1983. Monitoring during the past year, when compared with previous work dating to 1977, gives evidence for a major decline in mercury output from both Kilauea and Mauna Loa. This may have major significance for health and ecological concerns.



Sanford and Barbara Siegel take air samples to monitor mercury levels at HGP-A.

Hydrogen sulfide measurements, centered at HGP-A, have often been in the sensory range but have not at any time risen above 5 parts per billion (by volume) at 1 kilometer from the wellhead and only once exceeded 10 ppb at 100 meters distance downwind.

Concerns about hydrogen sulfide, especially perceptions that its odor is associated with toxic hazards, prompted the use of Rotorua, New Zealand, as a model community having long-term hydrogen sulfide exposure. The results of this study will be relevant to Hawaii County and other locales. A report on field data and health statistics acquired in New Zealand was issued in February 1984 as HNEI Symposium Paper No. 1, with the symposium presented in April. Preliminary findings showed that, although Rotorua and the surrounding geothermal region have far higher levels of hydrogen sulfide than the Puna District near HGP-A (50 ppb for more than 35 percent of the time in the city), there is no sign of health hazards, increased infant or adult mortality, or higher incidences of respiratory, cardiovascular, or neoplastic diseases compared with nonthermal New Zealand communities.

Various environmental monitoring and impact concerns have been addressed on Maui and Kauai. These include reassessment of air mercury baselines on Maui and hydropower development impact assessment on Kauai.

HAWAII DEEP WATER CABLE PROGRAM: ELECTRICAL CABLE CORROSION TESTING

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

PROJECT STAFF: Ko Moe Htun, Ph.D.
Pandurangasayi Nuh, B.S.
Lailani Wai, Student Help
Marsha Inouye, Student Help
Ken Yamabe, Student Help

PROJECT PERIOD AND FUNDING SOURCE: Funding for \$50,000 for FY 1983-84 was subcontracted through Parsons Hawaii and Hawaiian Electric to HNEI. This overall program has been ongoing since FY 1981-82 with major funding from USDOE and the State Department of Planning and Economic Development.

The Hawaii Deep Water Electrical Transmission Cable Demonstration Program is a research, development, and demonstration program that is being conducted by Hawaiian Electric Company and Parsons Hawaii to: (1) determine the feasibility of establishing an electrical transmission cable system in ocean depths of up to 7,000 feet and over a distance of more than 150 miles; (2) determine and solve engineering problems of deploying, retrieving, and repairing such a cable in the Hawaiian environment; and (3) develop criteria for commercial design, installation, and maintenance of such cable systems. A successful cable system of this nature could be used to transport electric power generated by geothermal or OTEC systems on the Big Island to Oahu, where most of the state's population and industry are located.

This project, a portion of Phase II-A of the HDWC Program, is intended to develop information on the resistance of different cable materials to the various destructive forces in the environment in order to insure long life of the installed cable. The areas of study are corrosion, abrasion, and fatigue of various types of metals that may be used as conductor, sheath, or armor material. The materials are being tested in the materials laboratories at the Mechanical Engineering Department at UHM and at the Natural Energy Laboratory of Hawaii where ocean waters obtained from both surface and deep ocean sources are used. These studies are all of a long-term nature and only preliminary results were developed during Phase II-A. Areas of ongoing investigation include:

1. Long-term corrosion testing of steel, copper, and aluminum alloys. These materials are typical of those that may be used for cable conductors, sheathing, or armor. Early results showed that the cupronickel samples had turned black but showed no fouling, and the aluminum plates had developed a film of aluminum hydroxide and some fouling. Clear evidence of the action of sulfate-reducing bacteria was seen for the steel, which would indicate the need for some corrosion protection system if carbon steel wires are to be used.

2. Crevice corrosion studies of stainless steel alloys. The stainless steel materials are also candidates for cable armoring. Corrosion studies are continuing using automatic monitoring of electrical potentials. At this stage, no reliable data have been obtained from this part of the study. Considerable sample duplication will be required to obtain reasonable reproducibility.

3. Abrasiveness of Hawaiian rocks to various potential cable armor steels. These studies will provide information required to armor cables properly to assure reliable operation in the Hawaiian ocean environment. Early indications are that austenitic stainless steels have better abrasion resistance than ferritic stainless steels of the same hardness; surface fatigue may be a more common wear mechanism than previously thought.

GRADUATE STUDENT ASSISTANTSHIPS

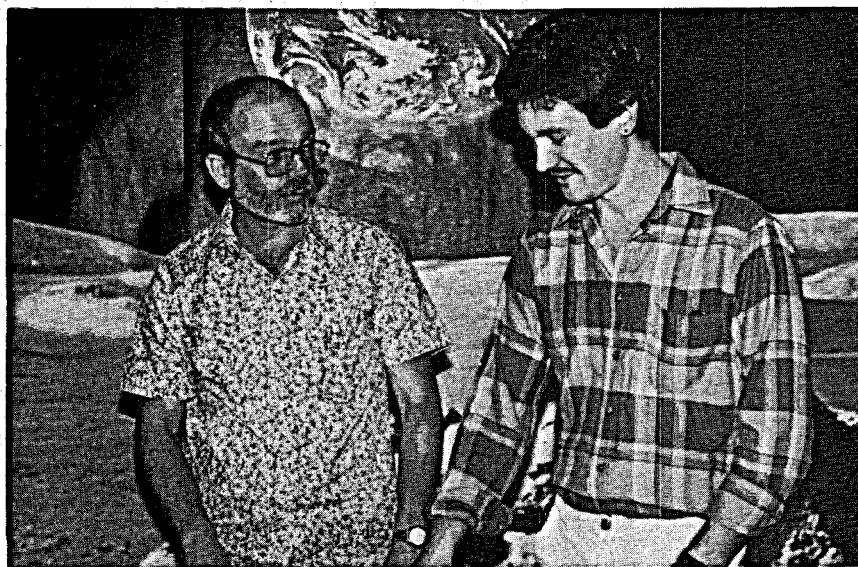
HNEI provided full graduate research assistantships to two master's candidates and one Ph.D. candidate in 1983-84. These students are pursuing research in OTEC, geothermal, and solar energy related topics. HNEI is planning to expand this program in 1985 and will recruit graduate students at the national level who want to pursue alternative energy research toward a master's degree in engineering or science, with potential for a doctorate.

The Cellular Floating Salt-Gradient Solar Pond Array (CFSGSPA) is a new type of solar pond being investigated by Ph.D. candidate Daniel D. Weeks in the UHM Department of Physics. This novel pond consists of individual, cylindrical solar ponds that float, secured and interconnected to one another, on a calm body of water such as an inland lake or a lagoon. The main focus of research is to model the thermodynamic behavior of a single cell. A proposal to perform an experiment to test the CFSGSPA has been completed. The experiment would be performed at the Natural Energy Laboratory of Hawaii on the Big Island in coordination with the one-acre Solar Pond Ocean Thermal Energy Conversion (SPOTEC) demonstration scheduled for construction there in the near future.

Sallie Edmunds, a master's candidate in the UHM Department of Urban and Regional Planning, is researching "Participatory Planning for Renewable Energy Development." While there is broad public support for developing Hawaii's renewable energy resources, community opposition has presented a serious obstacle in the siting of individual projects. This project addresses the issues involved in citizen participation in the planning and siting processes, using Hawaii's geothermal experience as a case analyzed in comparison with other case studies from the literature. The research investigated the timing, level, and nature of public involvement and some of the patterns that have emerged. It concluded that a citizen participation program should be an integral component of the planning process and should be tailored to the particular community because of differences in community cohesiveness, cultural patterns, lifestyles, and environmental awareness.



Sallie Edmunds with faculty advisor Peter Flachsbart examining a map in developing a framework for planning and community involvement in geothermal development siting process.



Daniel Weeks (right) conferring with his faculty advisor Thomas McCord on novel solar pond research.

Bruce Tsutsui, who is working toward a master's in marine geology at the Hawaii Institute of Geophysics, is investigating the nature and extent of apparent seabed movement in the area offshore of Kahe Point, Oahu, where a 40 MW OTEC pilot plant is planned. He is focusing on the changes caused by Hurricane Iwa in November 1982, which could have potentially significant effects on a large undersea structure such as the 30-foot diameter cold water pipe planned for the OTEC plant. Tsutsui took three research cruises into the site area to collect SeaMARC II side-scan sonar data, bathymetric data, and sediment piston cores. Analysis of the SeaMARC imagery, which is similar to an aerial photograph, shows apparent sediment movement near the proposed OTEC site. The study area will be mapped and the areal extent of sediment movements determined. The information will then be correlated with vertical information in the sediment piston cores collected in the site area. Opening and sampling of the cores, and micropaleontologic and stratigraphic analyses of these samples will be conducted as the next part of the study. The end result will be a general outline of sediment movements in the site area, which will aid in analysis of potential effects on planned OTEC structures.



Bruce Tsutsui (right) and faculty advisor William Coulbourn examining sediment samples collected at Kahe Point, Oahu.



EDUCATIONAL PROGRAMS

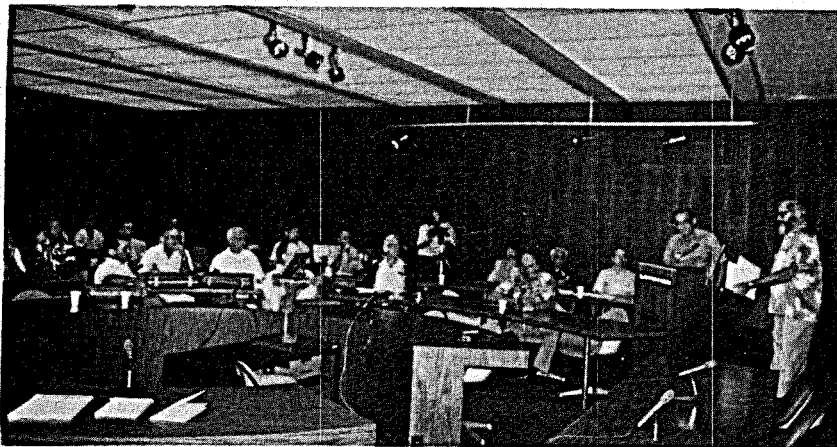
CONFERENCES/WORKSHOPS

INTERNATIONAL SYMPOSIUM ON HYDROGEN PRODUCED FROM RENEWABLE ENERGY, MAY 24-25, 1984

Hawaii's first International Symposium on Hydrogen Produced from Renewable Energy assembled researchers, government program administrators, and industry representatives from the U.S., Canada, Japan, Germany, and Austria to report on progress in hydrogen research and to consider Hawaii's potential as an international "pilot plant" for hydrogen production from renewables. More than eighty invited participants attended the two-day symposium, which was held at the East-West Center from May 24-25, 1984 and sponsored by HNEI, the East-West Center Resource Systems Institute, DPED, and PICHTR.

Researchers reviewed the progress of their respective hydrogen programs through papers on production methods, storage technology, and end-use applications. Although hydrogen is produced commercially, high costs presently limit the range of its use as a fuel. Papers delivered at the symposium revealed that current work in hydrogen fuel production is still primarily in the theoretical and laboratory stages.

Despite uncertainties affecting hydrogen's potential as the fuel of the future, symposium participants generally agreed that Hawaii's variety and abundance of renewable energy resources, its dependence on imported oil and concomitant high energy prices, and its small energy markets make the state an excellent testing ground for the commercialization of hydrogen produced from renewable sources and for utilization of hydrogen in a variety of applications. Participants expressed interest in developing cooperative programs with Hawaii. They also emphasized that shared research results would avoid duplication of efforts, thus speeding the entrance of hydrogen into the energy marketplace.



More than eighty representatives of government, academia, and the private sector heard researchers discuss progress in hydrogen research at Hawaii's first International Symposium on Hydrogen Produced from Renewable Energy held in May 1984.

PACIFIC BASIN BIOFUEL WORKSHOP, NOVEMBER 1-2, 1984

Biomass energy (or biofuel) is Hawaii's most flexible renewable energy resource. On November 1-2, 1984, HNEI co-sponsored a workshop to delve into the potential of this energy resource. Other sponsors of the program were DPED, the Estate of James Campbell, AMFAC Energy, C. Brewer and Company, Limited, and Molokai Ranch, Limited. Industry support enabled several out-of-state experts to participate in two days of intensive sharing, which contributed greatly to the success of the sessions.

One of the participants' tasks was to pool known information about the various species that can grow in Hawaii and to determine a priority list of new crops for test plantings and existing species for larger scale plantings. Prioritization of biomass resources took into account not only the crop's biomass fuel potential, but also the emerging technologies for converting biomass to fuels; the costs and benefits of alternative regimes of soil treatment, seed or nursery stock, planting techniques and equipment, irrigation, and fertilizers; and the ease of harvesting and transportation. Environmental, social, and legal impacts of biomass energy policies and the problem of competing uses for land were also considered.

New emphases suggested by knowledgeable scientists include the concept of energy cane, in which sugar is one of several products; use of sweet sorghum; production of jet fuels from biomass and methane from algae; sound ways to harvest and reforest unused forest lands, as well as ways to utilize abandoned pineapple and cane lands for energy plantations.

Workshop participants evaluated the information presented to set forth a plan of action for HNEI, the State, and USDOE, and to provide options for the sugar companies and other landowners. Program plans, possible funding sources, and needed legislative action, including tax incentives, were identified at the close of the sessions. These preliminary guidelines are being used as the basis for a model program for a "strategic biomass reserve" that will be included in the final workshop report published by HNEI.

Since the workshop, many follow-up activities have begun. An effort to launch a small tree farm on Molokai Homestead lands has been initiated. The Hawaiian Sugar Planters' Association (HSPA) has expressed an interest in participating in a test planting program on abandoned cane and pineapple lands to secure needed data. Communications have started for Hawaii's involvement in a regional bioenergy program, either in cooperation with the southwestern states, the Pacific and Caribbean Islands, or as a satellite to the already established Pacific Northwest BioEnergy Task Force. Finally, a comprehensive proposal to develop the concept of the energy plantation is being readied for submittal to the Department of Energy.

WORKSHOP ON BIOMASS ENGINEERING: THERMOCHEMICAL CONVERSION RESEARCH NEEDS, JUNE 1, 1984

The objective of the Kona workshop was to identify key research areas and directions in the field of biomass engineering, with the goal of helping the National Science Foundation, other government agencies, and individual researchers to develop a well-focused research agenda. Thermochemical utilization of biomass was emphasized at the Kona workshop, paralleling a similar NSF-sponsored workshop on biochemical utilization held at Purdue University.

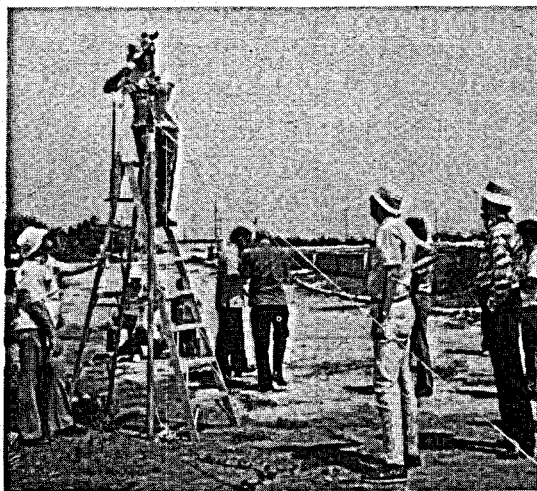
Seven topics were discussed by the twenty-three attendees during the four days of the workshop. The following six research themes surfaced in almost every discussion, suggesting emphases for future programs. (1) Product analysis: Sophisticated instrumentation and techniques are required to study the complex product slate of biomass pyrolysis reactors. (2) Product selectivity: Studies of the fundamental chemical mechanisms and pathways of pyrolysis, including research on whole biomass materials and model systems, should be emphasized to enhance product selectivity. (3) Kinetics and transport phenomena: Greater attention should be given to the elucidation of transport phenomena and their subtle effects on kinetic measurements. (4) Mathematical modeling: More attention should be given to sophisticated mathematical techniques in designing experiments, analyzing results, and predicting reactor behavior. (5) Novel reactor development: Novel reactor concepts should be designed to take advantage of the unique properties of biomass materials. (6) Standard samples: Heterogeneity of biomass materials is a major obstacle to progress of biomass pyrolysis; efforts to define and develop standards are needed.

HNEI has published a report which contains a detailed write-up of the workshop participants' conclusions and recommendations.

ANNUAL WIND ENERGY TECHNICAL WORKSHOP, JULY 28-30, 1983

HNEI, with the assistance of DPED, conducted the annual Wind Energy Technical Workshop on July 28-30, 1983. Sixty people attended the overview session on the first day, which consisted of technical discussion sessions on topics such as wind energy R&D in Hawaii and commercialization programs. Pressing local issues for wind energy users were raised during the discussions, notably: the ability of utility companies to provide quality energy on demand to its rate payers, concern that the commitment of wind farm developers might deteriorate after tax incentives are exhausted, questions of whether wind farms are set up as tax shelters rather than sound investments, and the possibility that new wind machines may burden consumers with higher electricity rates.

Field practicums were held on the following two days. On the 29th, 26 participants visited nine sites at Kahuku, Oahu, where wind machines are installed, and learned about maintaining wind energy conversion systems and measuring wind speed. A group of 16 flew to the Big Island on the 30th to view various wind turbines installed at Kahua Ranch and other sites in West Hawaii.



Participants to the 1983 Wind Energy Technical Workshop field practicum are given a demonstration on installation of a wind data accumulator.

ANNUAL WIND ENERGY TECHNICAL WORKSHOP, AUGUST 1-4, 1984

Wind commercialization efforts on the Big Island have brought national and international attention to Hawaii's wind farms. Issues involved in their ultimate success or failure were the subject of the annual HNEI Wind Energy Technical Workshop held on August 1-4, 1984. Each speaker at the workshop was asked to identify problems and to make recommendations that would help advance wind energy commercialization in Hawaii. Concerns brought up during the discussions related to technical, institutional, environmental, and financial/investment issues.

Ninety-three people attended the 1984 workshop, which added an extra day of technical sessions to the regular three-day workshop. In these sessions, UH faculty lectured on the engineering and aerodynamic principles related to wind energy. Another innovation was a hands-on computer session that demonstrated the HNEI Wind Energy Battery Storage (WEBS) model, a wind data reduction and energy generation program, and a business model that determines the potential profitability of a wind farm.

Following the morning computer session on August 3, workshop participants took a field trip to Kahuku to visit Don Avery's innovative fiberglass pump for a wind-mechanical water pumper at the U.S. Fish and Wildlife Sanctuary. Other wind machines seen were a Carter Wind System 25, ESI 54, and Jacob 10kW. The field trip to Maui on August 4 included stops at several WECS sites and concluded at the NifTAL (nitrogen fertilizer research) site, where a 150-foot meteorological tower was recently erected and four different machines are planned for various wind energy applications projects, two of which are already installed.

PHOTOVOLTAIC WORKSHOP, OCTOBER 27, 1983

Photovoltaics (PVs), according to workshop participants, show more promise for worldwide acceptance and application than any other solar technology. Characteristics that favor widespread use of PVs are the lack of moving parts, relatively simple design, few maintenance requirements, and insignificant levels of noise and other environmental pollution. PVs are allocated the largest share of the federal government's solar energy research budget. At the same time, advances and developments in public and private sector commercialization efforts are lowering costs, making them more affordable to a broader market.

With more than 300 users of PVs in Hawaii and frequent requests for information and assistance, DPED, assisted by HNEI, sponsored a timely workshop on PV technology. The main session was held on October 27, 1983, followed by four evening seminars (Nov. 14, Lihue, Kauai; Nov. 16, Kona and Nov. 17, Keeau, Big Island; and Nov. 22, Pearl City, Oahu). The seminars were led by D. Richard Neill, renewable energy advisor to DPED Energy Division, and Ronald Richmond, PV specialist with DPA Photovoltaic Power Company.

A Guidebook on PV Applications in Hawaii has been prepared by DPED to provide overview information about PVs, analyze the state's energy potential in this area, and give a comprehensive listing of current PV applications in Hawaii. Guidelines for purchasing or installing PV systems and their maintenance, notices of legal and safety considerations, and a list of PV manufacturers and dealers in Hawaii are included. Finally, sample calculations are offered to help determine the economics of PV systems, including direct and indirect costs, government incentives, and investment analyses.

ELECTRIC VEHICLE (EV) DRIVER TRAINING/MAINTENANCE WORKSHOP, SEPTEMBER 16-17, 1983

An EV Training Session held in mid-September 1983 was attended by 44 people. Participants represented State and federal governments, the UH system, private companies with EV fleets, and battery dealers. The diversity of this group enabled participants to form a network of contacts and a spare parts exchange.

USDOE officials provided an update of the federal EV program, stating that the broad demonstration program undertaken in 1979 was premature given the state of EV technology at that time. The new thrust of the program would be "test and evaluation" rather than "demonstration," with support concentrated at a few serious sites that would focus on data analysis and individual problem-solving. Another change involved the shift toward basic research, new technologies, retrofitting, and new designs.

The afternoon session was conducted by Warren Harhay who discussed battery and charger problems. He also gave detailed instructions on the care and upgrading of existing systems. At the hands-on training session held the next day, Harhay reviewed safety issues and explained the parts and operation of an EV by comparing it to an internal combustion engine.

DRIVER TRAINING/SHARING SESSION, MAY 4, 1984

Sixteen people attended the May 4th session aimed at providing information to new and potential drivers. There was a showing of a slide presentation developed by the U.S. Navy in which good driver training and positive driver attitude and commitment are identified as keys to effective EV performance. A report was given on the EV Users Task Force's Product Improvement Program in Washington, D.C. Recent activities in Hawaii were also reviewed, including the status of improvements that have been developed and tested, and are now proposed for field evaluation.

LECTURES

SYMPOSIUM PAPERS

In 1984, HNEI initiated a program to inform the general public about research projects related to topical energy issues. These papers are preliminary in nature and community input is solicited to guide the future of the projects. Each symposium paper released also involves a seminar conducted by the author(s).

Symposium Paper No. 1: Geothermal Hydrogen Sulfide and Health in Rotorua, New Zealand, April 25, 1984

The inaugural presentation was held on April 25, 1984 by Sanford Siegel, Chairman of the UH Botany Department and Barbara Siegel, Professor and Senior Researcher at the Pacific Biomedical Research Center, who spoke on "Geothermal Hydrogen Sulfide and Health in Rotorua, New Zealand," also published by HNEI in February 1984 as Symposium Paper No. 1. The Siegels write that their "report is concerned with the application of 'the Rotorua experience' to the concerns of Hawaii residents who are anxious about the impact of geothermal resource development near their homes, schools, farms and gardens. More specifically, it is addressed to concerns about the hazards of hydrogen sulfide emissions as they are associated with geothermal operations in areas such as Puna, Hawaii County." After determining representative levels of H₂S in Rotorua's atmosphere, the research design called for a review of the health and medical history of the area and comparison with nonthermal locations in New Zealand. While the Siegels claim that their report is only a first reconnaissance, their investigations thus far indicate that malodor notwithstanding, there is no evidence that exposure to H₂S is responsible for health impairments in Rotorua and its environs where H₂S levels are high by U.S. standards.

Symposium Paper No. 2: Energy Cane as a Multiple-Products Alternative, November 3, 1984

Symposium Paper No. 2 was presented by A. G. Alexander of the University of Puerto Rico on "Energy Cane as a Multiple-Products Alternative." Dr. Alexander's concept is somewhat controversial, as he advocates growing cane for energy and chemicals, rather than only sugar. The current plight of Hawaii's sugar industry makes the timing most appropriate for such a re-thinking.

ENERGY LECTURES SPONSORED BY HNEI, THE EAST-WEST CENTER, AND THE CORAL INDUSTRIES CHAIR OF RENEWABLE ENERGY RESOURCES

The third year of energy lectures sponsored jointly by HNEI, the Resource Systems Institute of the East-West Center, and the Coral Industries Chair of Renewable Energy Resources featured the following speakers.

"Solar Thermal Electric Penetration Issues," Richard Caputo, Visiting Researcher at Sandia National Laboratories, Livermore, CA, (on leave from the Jet Propulsion Laboratory, Pasadena, CA), December 12, 1983.

"Direct Solar Thermal Conversion Processes: Capturing Sunlight with Smoke," Arlon J. Hunt, Advanced Micromaterial Research and Development, Lawrence Berkeley Laboratory, University of California-Berkeley, April 27, 1984.

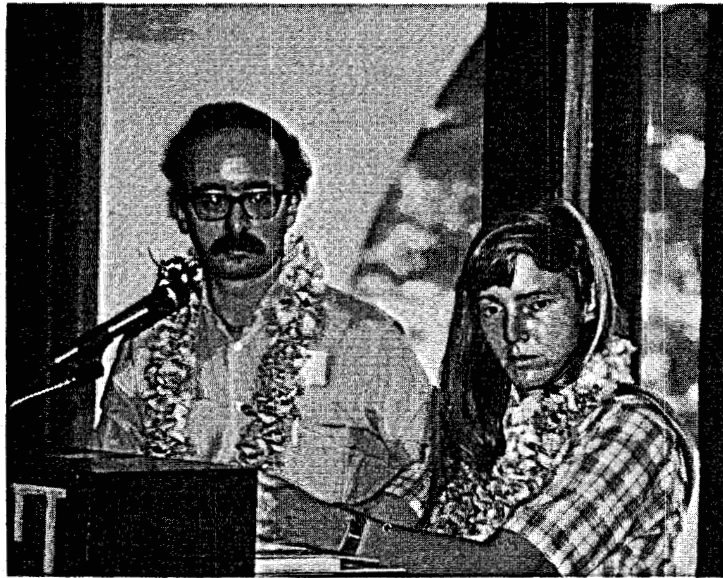
"Coproducts of Furfural and Ethanol from Bagasse by Acid Hydrolysis and Fermentation," John Becker, Flow Industries, June 26, 1984.

LOVINS LECTURE SERIES, NOVEMBER 21-29, 1983

An extended lecture series was presented in late November 1983 by Amory B. and L. Hunter Lovins, who have been described as two of "the Western world's most influential energy thinkers" by Newsweek. Their visit was sponsored by HNEI, the Coral Industries Chair of Renewable Energy Resources, the Hawaii State Department of Planning and Economic Development, and the East-West Center.

The husband and wife team of energy analysts, writers, and consultants currently operate the Rocky Mountain Institute at Old Snowmass CO, near Aspen. It is a non-profit institute which explores the links between energy, water, agriculture, security, and economics. Much of their work stems from Amory Lovins' study on energy titled *Soft Energy Paths*. He criticizes the "hard energy path" which is produced from nonrenewable resources—oil, natural gas, coal, and uranium—as wasteful production and consumption leading to repeated and worsening energy crises. The only way out of the situation is to follow a "soft energy path" which consists of (1) conservation of energy through improved efficiency; (2) intelligent use of present nonrenewable energy sources as "bridging fuels" during a transition period; and (3) rapid development of technologies for energy production from renewable sources.

Topics covered during four days of lectures and discussions in Hawaii were: "Energy and Sustainable Economic Development," "Least-cost Energy for the Developing Countries," "Energy Strategy for National Security," and "The University's Role in Energy Development."



Amory B. Lovins (left) and L. Hunter Lovins responding to audience questions during one of their four energy lectures.

GRADUATE PROGRAMS AT UHM

CERTIFICATE PROGRAM IN RENEWABLE ENERGY ENGINEERING

The University of Hawaii's Certificate Program in Renewable Energy Engineering has been designed to offer graduate students an opportunity to gain interdisciplinary energy expertise through coursework and scholarly research in geothermal, ocean, wind, photovoltaic, and biomass energy, while also completing advanced work in traditional disciplines.

UHM possesses the only endowed academic chair dedicated to the study of renewable energy resources. The Certificate program itself originated from the mandate establishing the Coral Industries Distinguished professorship. The Chair has since become a visible focus for a rigorous educational and research experience in renewable energy engineering, bringing together the intellectual resources of Professor M.J. Antal, current chairholder, and the unique facilities available throughout the state for demonstrating the vitality and practicality of renewables.

The program is open to graduate students enrolled in the College of Engineering, Architecture, Botany, Business Administration, Chemistry, Horticulture, Oceanography, Physics, Tropical Agriculture, and other related fields. Certificate candidates consult with an adviser from the program committee and their major adviser to select appropriate courses (five energy-related courses are required) and a research topic which satisfies the requirements of both programs.

Additional information may be obtained from Dr. Michael J. Antal, Jr., Coral Industries Professor of Renewable Energy Resources, HNEI, University of Hawaii, Honolulu, HI 96822.

RENEWABLE ENERGY DISTINGUISHED GRADUATE PROGRAM

HNEI recently created the Renewable Energy Distinguished Graduate Program which seeks outstanding students to participate in renewable energy research programs related to technological, economic, and environmental factors associated with geothermal, ocean, solar, wind, and biomass systems. In addition, post-doctoral researchers and university faculty members wishing to spend a sabbatical period in Hawaii are encouraged to express their interest by writing to the HNEI Director. Through this program, HNEI hopes to expand its range of contacts with individuals and organizations working in related fields. Another objective is to facilitate researchers' access to the excellent facilities at the University of Hawaii at Manoa (Renewable Resources Research Laboratory and Physical Electronics Laboratory, for example), the Natural Energy Laboratory of Hawaii at Ke-ahole Point, and the Puna Geothermal Research Facility in Puna.



INTERNATIONAL/INTERAGENCY COOPERATIVE PROGRAMS

SPARK MATSUNAGA FELLOWS IN RENEWABLE ENERGY ENGINEERING PROGRAM

The Spark Matsunaga Fellows in Renewable Energy Engineering (FREE) program represents a convergence of four major institutions with a common interest in building a renewable energy program of academic and research excellence. Together, they provide an overlapping and expanding circle of support: the College of Engineering (home base for many of the faculty), HNEI (State), the Renewable Energy Institute, Washington, D.C. (national), and PICHTR (international). The program is guided by a distinguished Board of Advisors, chaired by Senator Spark Matsunaga, and is governed by a steering committee representing the financial and institutional sponsors.

The FREE program involves foundation and corporate financial support for teaching and research positions to advance the development of renewable energy technologies. Professors' salaries (provided by UH) are matched with additional increments from program sponsors, thereby enabling the university to attract the finest in engineering faculty to work on critical energy problems in the ideal natural energy laboratory—Hawaii.

A \$250,000 grant by Hawaiian Electric Industries will fund the first Fellow. Additional contributions from the Atlantic Richfield Foundation, Chevron USA, and General Electric Company will allow the university to seek a second fellow. Support from Advanco Corporation is helping to cover the program's administrative expenses. The total pool of funds currently stands at approximately \$413,500.

The FREE program selection committee is in the midst of finalizing its selection of the first FREE fellow, a geothermal researcher who is being recruited specifically to assist in developing the Puna Geothermal Research Facility now under construction next to the HGP-A well. The search for a second fellow, specializing in the field of ocean energy, has also been initiated.

PICHTR ENERGY-RELATED ACTIVITIES

The Pacific International Center for High Technology Research (PICHTR) at the University of Hawaii was established by an act of the State Legislature in 1983. International in scope, PICHTR was designed to foster cooperation in high technology research, education and related activities among individuals and organized entities from the U.S. and the Pacific Basin. Two planning meetings held in 1984 saw the emergence of energy and resources technology as one of three technological components to be emphasized in PICHTR programs.

The first planning meeting convened in Tokyo on April 23-24, 1984. A strong contingent of federal officials from the departments of Energy, State, and Commerce and the National Science Foundation joined a Hawaii group in discussions with twenty-five Japanese delegates. The Hawaii team included State Rep. David Hagino, DPED Director Kent Keith, Board of Regents Chairman Stanley Mukai, UH President Fujio Matsuda, UH Associate Dean of Education Doris Ching, UH Engineering Dean Paul Yuen, and HNEI Director Patrick Takahashi.

Drs. Yuen, Ching, and Takahashi also visited with faculty from the University of Hong Kong and University of the Ryukyus. Potential joint energy projects were outlined based on interesting parallels between Okinawa (Ryukyu Islands) and Hawaii in geography, population, and energy needs. Yuen and Takahashi subsequently travelled to Taiwan to discuss cooperative projects.

As a follow-up to the April conference, PICHTR held a Technical Planning Meeting at the University of Hawaii at Manoa on August 15-16, 1984. Sixty-eight delegates from the United States, Japan, and Taiwan met to further refine recommendations made in Tokyo and to choose specific projects for collaborative research.

The Energy and Resources Technology group strongly endorsed projects in open-cycle ocean thermal energy and geothermal energy, both of which could be conducted profitably in conjunction with HNEI's ongoing work. Recommendations by two other working groups also have implications for renewable energy research: development of an unmanned, untethered deep-ocean vehicle (possibly for use in OTEC plant siting) by the Information Technology group, and crop improvement and pest management in tropical agriculture and aquaculture (possibly to improve biomass yield) by the Biotechnology group.

TRI-STATE SOLAR ENERGY CONSORTIUM

HNEI, the Florida Solar Energy Center (FSEC), and the New Mexico Solar Energy Institute (NMSEI), three of the nation's top solar research centers, signed a cooperative agreement in July 1983. Spearheading the cooperative effort were the directors of the three energy organizations: Dr. Patrick Takahashi (HNEI), Dr. David Block (FSEC), and Dr. Harry Zwibel (NMSEI). The purpose of the agreement is to coordinate mutual interests in continued development of solar resources over the five-year term of the agreement.

The consortium concept developed out of a recognition that implementation of solar energy technologies would occur at the state and local levels and, moreover, that coordination is essential to achieve coherent national R&D and implementation programs. Geographically, the consortium stretches across the sunbelt from the extreme east to the extreme west, and have further tie-ins with other areas, such as the Pacific Basin and the Caribbean.

The agreement seeks to enhance the solar programs of the respective states and the nation by bringing together the complementary skills of each organization. Joint activities, such as research personnel exchange, proposal/program coordination, networking of R&D activities and information, and performance monitoring of experimental solar facilities are being considered. Technological areas of interest to the consortium members are hydrogen fuel, OTEC, photovoltaics, energy-efficient building design, and wind energy. As recent outgrowths of the consortium agreement, HNEI and FSEC have jointly submitted a hydrogen proposal to the Department of Energy, while HNEI and NMSEI have begun collaboration on a geothermal technology transfer proposal.

In addition, HNEI has been engaged in other types of informal interagency agreements. Examples of these include:

- Arrangement with the Denver-based Solar Energy Research Institute (SERI) to act as its outpost in the Pacific for testing and evaluating newly developed solar equipment.
- Agreement with Brookhaven National Laboratory, Long Island, New York, to assist in hydrogen research.
- Partnership with Argonne National Laboratory, Chicago, Illinois, in ocean energy research.



PUBLICATIONS

TECHNICAL REPORTS AND SYMPOSIA PRINTED BY HNEI

Final Report on Hawaiian Photovoltaic Residential Systems and Evaluation. No. HNEI 84-02. P.K. Takahashi, A. Seki, and G.D. Curtis. June 1984.

Report of the Kona Workshop—Biomass Engineering: Thermochemical Conversion Research Needs. M.J. Antal, Jr., Chairman. June 1984.

Geothermal Hydrogen Sulfide and Health in Rotorua, New Zealand. Symposium Paper No. 1. No. HNEI 84-S01. S.M. Siegel and B.Z. Siegel. February 1984.

International Symposium on Hydrogen Produced from Renewable Energy. Preliminary Proceedings. May 1984.

PUBLICATIONS AND PRESENTATIONS RESULTING FROM HNEI PROJECTS

Antal, M.J. 1983. "Biomass Pyrolysis. A Review of the Literature—Part 1: Carbohydrate Pyrolysis." *Advances in Solar Energy*, K.W. Boer and J.A. Duffie, eds. American Solar Energy Society, Vol. 1, New York.

_____. 1983. "The Effects of Reactor Severity on the Gas Phase Pyrolysis of Cellulose and Kraft Lignin Derived Volatile Matter." *Industrial and Engineering Chemistry Product Research and Development*, Vol. 22, pp. 366-375.

_____. 1984. "Biomass Pyrolysis. A Review of the Literature—Part 2: Lignocellulose Pyrolysis." *Advances in Solar Energy*, in press.

_____. 1984. "A Review of the Vapor Phase Pyrolysis of Biomass Derived Volatile Matter." *Proceedings of the Fundamentals of Thermochemical Biomass Conversion International Conference*, in press.

_____, and L. Hofmann. 1984. "Numerical Simulations of the Performance of Solar Fired Flash Pyrolysis Reactors." *Solar Energy*, in press.

_____, L. Hofmann, J.R. Moreira, C.T. Brown, and R. Steenblik. 1983. "Design and Operation of a Solar Fired Biomass Flash Pyrolysis Reactor." *Solar Energy*, Vol. 30, pp. 299-312.

_____, M.W. Hopkins, and J.G. Kay. 1984. "Radiant Flash Pyrolysis of Biomass Using a Xenon Flashtube." *Journal of Applied Polymer Science*, in press.

_____, and V. Kothari. 1983. "Numerical Studies of the Flash Pyrolysis of Cellulose." Preprints of the American Chemical Society Division of Fuel Chemistry, Washington, D.C.

- Antal, M.J., and W.S.-L. Mok. 1983. "Effects of Pressure on Biomass Pyrolysis. I. Cellulose Pyrolysis Products." *Thermochim. Acta.*, Vol. 68, pp. 155-164.
- _____, and W.S.-L. Mok. 1983. "Effects of Pressure on Biomass Pyrolysis. II. Heats of Reaction of Cellulose Pyrolysis." *Thermochim. Acta.*, Vol. 68, pp. 165-186.
- _____, Y. Stein, and M. Jones. 1983. "A Study of the Gas Phase Pyrolysis of Glycerol." *Journal of Analytic and Applied Pyrolysis*, Vol. 4, pp. 283-296.
- Avery, D., D.R. Neill, and P.K. Takahashi. 1983. "Development of Advanced Wind-Water Pump Machines in Hawaii." *Proceedings of the International Solar World Congress*, Perth, Australia. August 1983.
- Curtis, G.D. 1984. "Wind Energy-Battery Storage (WEBS) System Study and Design Project Summary Update." Presented at the Sixth U.S. DOE Battery and Electrochemical Contractors' Conference, Washington, D.C. June 1984.
- De Carlo, E.H., G.M. McMurtry, and H.-W. Yeh. 1983. "Geochemistry of Hydrothermal Deposits from Loihi Submarine Volcano, Hawaii." *Earth and Planetary Science Letters*, Vol. 66, pp. 438-449.
- _____, and D.M. Thomas. 1984. "Removal of Arsenic from Geothermal Waters by Adsorptive Bubble Flotation with Colloidal Ferric Hydroxide." *Journal of Environmental Science and Technology*, in press.
- Engle, G.A. 1984. "Electrochemical Investigation into the Properties of Some Transition Metal Hydrides." M.S. thesis, Mechanical Engineering, University of Hawaii at Manoa.
- Freeman, R.S. 1983. "Weight Loss, Potentiostatic Polarization, and Impedance Measurements of Three Aluminum Alloys." M.S. thesis, Mechanical Engineering, University of Hawaii at Manoa.
- Hawaii Department of Planning and Economic Development. 1983. *Agri-Energy Research and Development in Hawaii*. Prepared by Department of Planning and Economic Development, Hawaii Natural Energy Institute, and Department of Agriculture. November 1983.
- Imada, J. 1984. "Numerical Modeling of Groundwater in the East Rift Zone of Kilauea Volcano, Hawaii." M.S. thesis, Geology and Geophysics, University of Hawaii at Manoa.
- Kearney, T.J., and F.J. Sansone. 1984. "Analysis and Formation Mechanisms of Mixed N-Halogenated Methylamines." *Water Chlorination, Environmental Impact and Health Effects*, Vol. 5, R. Jolley, et al., eds., in press.
- Lancaster, M.S. 1984. "The Fabrication and Testing of the Ridged Grid Solar Cell." M.S. thesis, Electrical Engineering, University of Hawaii at Manoa.
- _____, and J.W. Holm-Kennedy. 1984. "The Fabrication and Testing of the Ridged Grid Solar Cell." Hawaii Natural Energy Institute Report, University of Hawaii at Manoa.

- Larsen-Basse, J., and K.F. Lam. 1984. "Corrosion Tests in Hawaiian Geothermal Fluids." *Proceedings of the International Conference on Metallic Corrosion*, Vol. 3, pp. 641-648, Toronto, Canada. June 1984.
- Laws, E.A. 1984. "Research, Development and Demonstration of Algal Production Raceway (APR) Systems for the Production of Hydrocarbon Resources." Solar Energy Research Institute Subcontract Report. February 1984.
- _____, K.L. Terry, J. Wickman, and M. Chalup. 1983. "A Simple Algal Production System Designed to Utilize the Flashing Light Effect." *Biotech. Bioeng.*, Vol. 25, pp. 2319-2335.
- Liebert, B.E. 1983. "Real Time Acquisition and Calculation of the Impedance of Electrochemical Systems, Abstract." *J. Electrochem. Soc.* Vol. 130, p. 339C.
- Manghnani, M.H., and W.C. Luth. 1984. "Elastic, Anelastic, Electrical and Thermal Properties of Kilauea Iki Lava Lake Samples." Abstracts of the papers presented at the International Symposium on Observation of the Continental Crust through Drilling, Tarrytown, New York. May 1984.
- _____, H. Sato, and C.S. Rai. 1983. "Ultrasonic Measurements of V_p and Q_p^{-1} on an Alkalic Basalt Melt: Indirect Deduction of Viscosity Values, EOS." *Trans. Amer. Geophys. Union*, Vol. 64, p. 848.
- McMurtry, G.M., D. Epp, and D.M. Karl. 1983. "Project Pele: Studies of the Hydrology, Chemistry and Microbiology of Geothermal Systems on the Submarine Rift Zones of the Hawaiian Chain." *Sea Grant Quarterly*, Vol. 5, pp. 1-8.
- Neill, D.R. 1983. "Analysis of the Difficulties to Install WECS in Hawaii." Presented at the American Wind Energy Association Annual Conference, San Francisco. October 1983.
- _____. 1983. "Utility Interface Concerns and Programs Under Way in Hawaii to Help Address These Concerns." Presented at the American Wind Energy Association on National Conference, San Francisco. October 1983.
- _____. 1984. "Hawaii—On the Threshold of Wind Farming." Presented at the American Solar Energy Society Conference, Anaheim, California. June 1984.
- _____. 1984. "Hawaii's Abundant Renewable Energy Resources." Presented at the International Symposium on Hydrogen Produced from Renewable Energy, Honolulu. May 1984.
- _____, and P.K. Takahashi. 1983. "Progress in Wind Energy Utilization in Hawaii." *Proceedings of the International Solar World Congress*, Perth, Australia. August 1983.
- Sansone, F.J., and T.J. Kearney. 1984. "Chlorination Kinetics in Surface and Deep Tropical Seawaters." *Environ. Sci. Technol.*
- _____. 1984. "Unusual Chlorine Kinetics of Tropical Seawater, and the Potential Environmental Effects." *Proceedings of the Pacific Congress on Marine Technology*, Marine Technology Society, Honolulu. April 1984.

Siegel, B., M. Lasconia, E. Yaeger, and S. Siegel. 1984. "The Phytotoxicity of Mercury Vapor: Some Developmental Aspects." *Water, Air and Soil Pollution*, in press.

Siegel, S., and B. Siegel. 1983. "Vegetation and the Atmospheric Cycling of Mercury." *Adv. Space Res.* Vol. 3, pp. 135-139.

_____ 1984. "Annual Mercury Flux at the Kilauea Main Vent—A First Approximation." *Nature*, in press.

_____ 1984. "Differential Elimination of Mercury During Maturation of Leguminous Seeds." *Phytochemistry*, in press.

_____, and A. Bazzan. 1984. "Volatile Release of Elemental Mercury: Significance for Allelopathy and Detoxification." Presented at the Society for Chemical Ecology First Annual Meeting, University of Texas, Austin. June 1984.

_____, and W. Dendle. 1984. "Mercury from Hawaiian Volcanoes: Is the Output Declining?" *Pacific Science*, in press.

Takahashi, P.K. 1983. "A Preliminary Research Proposal to Establish an International Program on the Production, Storage, Transmission and Utilization of Hydrogen Derived from Renewable Energy Sources." *Proceedings of the International Symposium on Hydrogen Energy*, Tokyo. September 1983.

_____. 1983. "The Pacific International Center for High Technology Research as the Site for International Collaboration in the Development of Renewable Hydrogen." *Proceedings of the International Energy Agency, Implementing Agreement Hydrogen Task Workshop*, Ispra, Italy. September 1983.

_____, and D.R. Neill. 1983. "Importance of Renewable Energy in Hawaii's Future." *Proceedings of the International Solar World Congress*, Perth, Australia. August 1983.

Thampi, S. 1984. "Dynamic Positioning Using Environmental Forces." M.S. thesis, Ocean Engineering, University of Hawaii at Manoa. May 1984.

