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Ocean Energy Program Summary

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Contents

Introduction

The oceans are the world's largest solar energy collector and storage system. Covering 71% of the earth's surface, this stored energy is realized as waves, currents, and thermal and salinity gradients. The purpose of the federal Ocean Energy Technology (OET) Program is to develop techniques that harness this ocean energy in a cost-effective and environmentally acceptable manner. The OET Program seeks to develop ocean energy technology to a point where the commercial sector can make competent assessments of whether applications of the technology are viable energy conversion alternatives, or supplements, to systems currently in use.

Past studies conducted by the U.S. Department of Energy (DOE) have identified ocean thermal energy conversion (OTEC) as the largest potential contributor to U.S. energy supplies from the ocean resource. As a result, the OET Program also continues to monitor and study developments in wave energy, ocean current, and salinity gradient concepts but is not actively developing these technologies at the present time. Before FY 1982, the Program emphasized the development of the closed-cycle OTEC system because it was judged to have the greatest potential of the known ocean energy options for significant near-term energy contribution. However, more recent evaluations of these research areas indicate that open- and closed-cycle OTEC systems offer different paths for attaining the same cost-of-service goal. Current Program emphasis has shifted toward open-cycle power system research because the closed-cycle system is at a more advanced stage of development and has already attracted industrial interest.

During FY 1988, the OET Program focused primarily on the technical uncertainties associated with near-shore open-cycle OTEC systems ranging in size from 2 to 15 MW_e. Activities were performed under three major program elements: (1) Thermodynamic Research and Analysis, (2) Experimental Verification and Testing, and (3) Materials and Structures Research. These efforts addressed a variety of technical problems whose resolution is crucial to demonstrating the viability of open-cycle OTEC experiments installed at DOE's Seacoast Test Facility (STF) at the Natural Energy Laboratory of Hawaii (NELH), Keahole Point, Hawaii. These experiments will both validate analytical models and explore the performance boundaries of critical components in seawater. These efforts form the beginning stages of a three-phase experimental effort that will ultimately lead to the construction and testing of a 165-kW_e (gross) open-cycle OTEC net power-producing experiment. These experiments and their associated supporting activities will have the participation of the Pacific International Center for High Technology Research (PICHTR). Also in FY 1988, the installation of an upgraded seawater supply system was completed at the STF under the joint sponsorship of DOE, PICHTR, and the state of Hawaii. This system currently supplies seawater for the OTEC experiments at the STF as well as for various aquaculture and mariculture experiments at the NELH and the adjacent Hawaii Ocean Science and Technology Park. This system has sufficient capacity to supply both the warm and cold seawater needs of the 165-kW_e net power-producing experiment.

OET Program research activities for FY 1988 are described in the individual project descriptions that follow. Highlights of particular note are listed below. Additional information on the federal OET Program is available in the *Federal Ocean Energy Technology Program Multiyear Program Plan FY 1985–89.*

This summary is divided into two major sections. The first section includes the individual project descriptions for each activity grouped by directing organization. The second section provides a list of publications also grouped by directing organization.

Organizational Relationships

The federal OET Program is managed by DOE's Wind/Ocean Technologies Division within the Office of Solar Electric Technologies under the direction of the deputy assistant secretary for renewable energy. Day-to-day research activities are conducted by the Solar Energy Research Institute in Golden, Colo., and Argonne National Laboratory in Argonne, Ill. In addition, PICHTR is participating in various aspects of the 165-kW_e open-cycle OTEC project at the STF.

FY 1988 Research Accomplishments

Solar Energy Research Institute

- Completed construction of the heat- and mass-transfer scoping test apparatus.
- Completed scoping tests on the evaporator, mist eliminator, surface condenser, and warm water predeaerator (with PICHTR).
- Initiated scoping tests on the direct-contact condenser (with PICHTR).
- Initiated analysis efforts toward specification of the evaporator, condenser, and seawater supply subsystems for the net power-producing experiment (with PICHTR).
- Initiated the preliminary design of a radial-inflow 165-kW_e open-cycle OTEC turbine for the net power-producing experiment.
- Completed the preliminary design of a radial-outflow innovative open-cycle OTEC turbine.

Argonne National Laboratory

- Refined performance prediction methods for the cross-flow OTEC surface condenser based on experimental data from scoping tests.

- Prepared an interim report on the results of the biofouling and corrosion test program.
- Developed an analysis method for designing integrated systems to remove noncondensable gases from a hybrid closed- and open-cycle OTEC system.
- Began assembling the test apparatus for single-channel studies of noncondensable gases in surface condensers.
- Designed and installed water and vacuum systems in the heat- and mass-transfer scoping test apparatus to support direct-contact condenser experiments.

DOE/State of Hawaii/PICHTR

- Completed installation of an upgraded seawater supply system for the STF.

FY 1988 Contract Descriptions

Solar Energy Research Institute

165-kW_e Turbine Design

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: C. Castellano

Telephone: (202) 586-6265

Contractor:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Principal Investigator: D. Bharathan

Telephone: (303) 231-1758

Contract Number: DE-AC02-83CH10093

Current Contract Period:
From: 10/01/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	$226,000	DOE
FY 1987	$40,612	DOE
FY 1988	$276,537	DOE

Objectives:

To establish a performance specification and initiate the preliminary design of a turbine test article for an open-cycle OTEC (OC-OTEC) net power-producing experiment (NPPE) and to identify and evaluate innovative turbine concepts that can significantly increase the power output, decrease the cost of the turbine system, or both.

Approach/Background:

Prepare conceptual design and specification of a turbine test article for NPPE and develop the aero/thermodynamic relationships required to establish the parametric ranges encompassing the potential turbine designs to satisfy 165 kW_e. Overall studies should result in compatible mass flows, power densities, power levels, efficiencies, steam velocities, and thermodynamic conditions consistent with the physical turbine characteristics of diameter, blade height, exhaust area, and number of stages.

Status/FY 1988 Accomplishments:

Three university student teams investigated advanced innovative turbine concepts for achieving long-term cost reduction for the turbine. The SERI effort was aimed at examining radial-outflow turbine design as a potentially low-cost turbine option for OC-OTEC.

Major Project Reports:

- Carmichael, A.D., and T.R. Brehm, Sept. 1988, *OTEC Open Cycle Turbine: Innovative Design for Cost Reduction*, report no. 88-5, Cambridge, MA: Department of Ocean Engineering, Massachusetts Institute of Technology.
- OTEC Group, Apr. 1988, *Ocean Thermal Energy Conversion (Turbine Design)*, Philadelphia, PA: Department of Mechanical Engineering, University of Pennsylvania.
- Schobeiri, I.T., 1988, *Optimum Design of a Low Pressure, Double Inflow, Radial Steam Turbine for Open Cycle Ocean Thermal Energy Conversion*, College Station, TX: Department of Mechanical Engineering, Texas A&M University.

Summary Date: December 1988

165-kW$_e$ Turbine Development Contract

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: D. Bharathan

Telephone: (303) 231-1758

Contractor:
Mechanical Technologies, Inc.
968 Albany - Shaker Road
Latham, NY 12110

Principal Investigator: W. Koebbeman

Telephone: (518) 899-2976

Contract Number: XM-8-18072-1

Current Contract Period:
From: 08/01/88 **To:** 04/30/89

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	-0-	—
FY 1988	$92,007	DOE

Objectives:

To design, build, and install a steam turbine/electrical generator unit into an OTEC experimental facility that will generate net electrical power.

Approach/Background:

The turbine represents a major cost in an open-cycle OTEC power system. Current concepts for a low-pressure turbine focus on axial machines. Estimates of turbine cost for a 10-MW plant are approximately 35% of total plant capital cost. As a result of design studies, a turbine test article of 165-kW$_e$ capacity was identified as being an appropriate size to provide technical data that is scalable to commercial sizes and able to be tested in the facilities under development at the Seacoast Test Facility. The design and construction of this test article can be completed using technical capability presently available in the turbo machinery industry.

Status/FY 1988 Accomplishments:

Generated specifications for the design and development of the turbine with the help of three leading experts in the turbine area. The specifications included identifying the thermodynamic states of steam at inlet and outlet conditions as projected using a model for the 165-kW$_e$ system. Awarded contract to Mechanical Technologies, Inc., in August 1988. Current work is progressing on the Phase I conceptual and preliminary designs.

Major Project Reports: None.

Summary Date: December 1988

Open-Cycle OTEC Experiments

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: C. Castellano

Telephone: (202) 586-6265

Contractor:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Principal Investigator: F. Zangrando

Telephone: (303) 231-1761

Contract Number: DE-ACO2-83CH10093

Current Contract Period:
From: 10/01/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	$998,000	DOE
FY 1987	$427,338	DOE
FY 1988	$660,316	DOE

Objectives:

To develop high-performance components and analytical models of components in the parameter range suitable for OC-OTEC applications, to verify the performance and model predictions, and to document the experimental and analytical work. The established data base will be used in system analysis activities in support of the net power-producing experiment (NPPE) and small-scale OC-OTEC system design.

Approach/Background:

The heat- and mass-transfer scoping test apparatus (HMTSTA) became operational in FY 1987 at the Seacoast Test Facility (STF) to quantify the performance of prototypical OC-OTEC components operating in seawater. Phase I tests were directed toward assessing the performance of the evaporator, mist eliminator, predeaerator, and surface condenser. Phase II, which is in progress and will be completed in FY 1989, is directed toward the direct-contact condenser (DCC) performance.

Status/FY 1988 Accomplishments:

Completed Phase I experiments in FY 1988. Analyzed the data collected, comparing the results to fresh water data and model predictions. Produced desalinated water at the HMTSTA, which was a first for an OTEC facility. Constructed and installed DCC equipment at the STF, concluded acceptance tests, and initiated tests on the DCC unit (Phase II). Results of all the component tests have shown good component performance and good agreement with the performance models for each component. In addition, completed and published a comprehensive report on the performance model for DCC condenser stages.

Major Project Reports:

- Bharathan, D., July 1988, "Progress in the Claude-Cycle OTEC Research," SERI/TP-253-3379, Golden, CO: Solar Energy Research Institute. Presented at the American Society of Mechanical Engineers Conference on Offshore Mechanics and Arctic Engineering (OMAE Europe '89), The Hague, The Netherlands, March 19-23, 1989.

- Bharathan, D., and H. Link, July 1988, "Preliminary Results of Seawater Evaporation in Single and Multiple Spouts," SERI draft letter report, Golden, CO: Solar Energy Research Institute.

- Bharathan, D., B.K. Parsons, and J.A. Althof, Oct. 1988, *Direct-Contact Condensers (DCC) for Open-Cycle OTEC Applications*, SERI/TR-252-3108, Golden, CO: Solar Energy Research Institute.

- Kreith, F., and D. Bharathan, Feb. 1988, "Heat Transfer Research for Ocean Thermal Energy Conversion," *Journal of Heat Transfer*, Vol. 110: pp. 5-22, 1986 Max Jacob Memorial Award Lecture. Presented at the ASME/JSME Thermal Engineering Joint Conference, Honolulu, Hawaii, March 22-27, 1987.

- Pesaran, A.A., and H. Link, Oct. 1988, "Preliminary Surface Seawater Deaeration Results under OC-OTEC Conditions," SERI draft letter report, Golden, CO: Solar Energy Research Institute.

- Valenzuela, J.A., T. Jasinski, W. Stacey, B. Patel, and F. Dolan, June 1988, *Design and Cost Study of Critical OC-OTEC Plant Components*, SERI/STR-253-3246, Golden, CO: Solar Energy Research Institute.

Summary Date: December 1988

Heat- and Mass-Transfer Scoping Test Apparatus (HMTSTA) Support, Subcontracts, and Materials

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: F. Zangrando

Telephone: (303) 231-1761

Contractor:
Research Corporation of the University of Hawaii
1110 University Ave., Suite 402
Honolulu, HI 96822

Principal Investigator: T. Daniel

Telephone: (808) 329-7341

Contract Number: XX-8-07253-1

Current Contract Period:
From: 12/01/87 **To:** 11/30/88

Contract Funding:		Source:
FY 1986	$200,000	DOE
FY 1987	$300,000	DOE
FY 1988	$505,226	DOE

Objective:

To provide subcontract and material support to perform seawater tests on key open-cycle components assembled at the Natural Energy Laboratory of Hawaii (NELH) on the HMTSTA.

Approach/Background:

Provide subcontracted support at NELH to carry out experiments on the evaporator, mist eliminator, predeaerator, and surface and direct-contact condensers at the HMTSTA test facility. This task is the subcontract activity associated with the open-cycle OTEC experiments (see "Open-Cycle OTEC Experiments" contract description in this section) and provides funding for seawater supply provision and facilities, as well as the material, hardware, and instrumentation to support experimental operations for this effort.

Status/FY 1988 Accomplishments:

Provided administrative support to carry out tests at the Seacoast Test Facility, including evaluating requests for hardware and instrumentation and expediting such requests to complete testing in a timely manner. Completed testing of all Phase I components with operational support from NELH. Began testing the direct-contact condenser (DCC). Completed and tested modifications of the Phase II equipment for the HMTSTA. NELH supported erection of the DCC tower and installation of DCC equipment, lighting, electrical supply, data acquisition, maintenance, and wiring.

Major Project Report:

- Link, H. 1988, *The Safe Operating Procedure (SOP) for the HMTSTA Phase I and Phase II*, Phase II revision completed in November, SERI internal report, Golden, CO: Solar Energy Research Institute.

Summary Date: December 1988

Net Power-Producing Experiment (NPPE) System Development

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: L. Lewis

Telephone: (202) 586-6263

Contractor:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Principal Investigator: A. Trenka

Telephone: (303) 231-1866

Contract Number: DE-AC02-83CH10093

Current Contract Period:
From: 10/01/87 **To:** 09/30/88

Contract Funding:		**Source:**
FY 1986	-0-	—
FY 1987	-0-	—
FY 1988	$79,936	DOE

Objective:

To provide system integration engineering planning and direction that will address the specifics of the NPPE performance, subcomponent interface, system control, system stability and dynamics, and hardware design and integration.

Approach/Background:

One of the key technical objectives of DOE's Ocean Energy Technology Program is to experimentally verify open-cycle OTEC technology by validating heat- and mass-transfer predictions and power generating techniques, initially at the component level followed by integrated systems tests. The issues associated with subsystem interface, overall system performance, control system stability, subcomponent structural response, and other system-related interactions will be addressed from the perspective of developing a NPPE at the 165-kW_e (gross) level.

Status/FY 1988 Accomplishments:

Finalized a conceptual baseline configuration for the NPPE and provided an initial conceptual criteria for developing the turbine design requirement. Began studies on several alternatives to the conceptual baseline that hold promise of improved system efficiency and reduced costs. Assigned a critical assessment of the baseline configuration to the Pacific International Center for High Technology Research (PICHTR) (see PICHTR contract descriptions in this section).

Major Project Reports:

- Trenka, A.R., A. Thomas, and L. Vega, 1988, "Technical Developments of OTEC Systems," *Proceedings, International Renewable Energy Conference (IREC)*, Honolulu, HI, September 18-24.
- Lewis, L.F., L. Trimble, and J. Bowers, 1987, "Open-Cycle OTEC Seawater Experiments in Hawaii," *Proceedings, MTS/IEEE Oceans '87 Conference*, Halifax, Nova Scotia, Canada, September 28—October 1.

Summary Date: December 1988

Florida Solar Energy Center (FSEC) Subcontract

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: A. Trenka

Telephone: (303) 231-1866

Contractor:
Florida Solar Energy Center
300 State Road 401
Cape Canaveral, FL 32920

Principal Investigator: D. Block

Telephone: (305) 783-0300

Contract Number: XX-7-07056-1

Current Contract Period:
From: 05/01/87 **To:** 02/01/88

Contract Funding:		Source:
FY 1986	$45,000	DOE
FY 1987	-0-	—
FY 1988	-0-	—

Objectives:

To evaluate candidates in the Caribbean for a Seawater Research Test Facility (SRTF) and generate specifications for a SRTF.

Approach/Background:

Collect all pertinent data on potential site locations from existing studies and resources and expand the existing data base by visiting the site. Prepare a final report summarizing the results, recommending site(s), and providing specifications for a SRTF.

Status/FY 1988 Accomplishments:

Completed project early in FY 1988 and submitted a draft final report documenting data collected and potential and recommended sites. Also presented a SRTF cost and specification for the recommended site.

Major Project Reports: None.

Summary Date: December 1988

Analysis of Cold-Water Pipe (CWP) Options

Project/Area/Task:
Materials and Structures Research

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: L. Lewis

Telephone: (202) 586-6263

Contractor:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80403

Principal Investigator: B. Shelpuk

Telephone: (303) 231-1759

Contract Number: DE-ACO2-83CH10093

Current Contract Period:
From: 10/01/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$21,000	DOE
FY 1988	$30,000	DOE

Objectives:

To identify alternative approaches for constructing and installing seawater systems for 10-15 MW_e -sized OTEC plants and to establish a baseline description of the technical approach and costs associated with the near-shore and offshore portions of the system.

Approach/Background:

Identify a team of expert contractors, laboratories or both to help define key research issues relating to state-of-the-art deployment techniques, materials, and other options for CWP technology.

Status/FY 1988 Accomplishments:

Considered seawater systems in the 3-5.25 m diameter range at the CWP workshop sponsored by SERI and the Pacific International Center for High Technology Research (PICHTR). Determined that satisfactory techniques for pipe installation in the near-shore zone currently exist; additional analytical modeling, simulation, and experimentation are required for offshore segments; DOE cost goals currently can only be met for much larger diameter pipes; and innovative solutions must be found for these intermediate-size pipes.

Major Project Report:

- Nihous, G., and L. Vega, Oct. 1988, *Bottom-Mounted OTEC Seawater System Workshop Summary Report*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

Summary Date: December 1988

Pacific International Center for High Technology Research (PICHTR)—System Analyses

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: A. Trenka

Telephone: (303) 231-1866

Contractor:
Pacific International Center for
High Technology Research
2875 South King Street
Honolulu, HI 96826

Principal Investigator: L. Vega

Telephone: (808) 945-7635

Contract Number: XX-8-07206-1

Current Contract Period:
From: 01/15/88 **To:** 07/15/89

Contract Funding:		Source:
FY 1986	$30,000	DOE
FY 1987	$471,000	DOE
FY 1988	$810,000	DOE

Objectives:

To implement system performance models that generate designs for hardware and test plans for experiments relevant to a system-level open-cycle OTEC (OC-OTEC) experiment; develop a conceptual design of an open-cycle turbine base using existing hardware; assess conceptual plant designs for small, multi-megawatt OC-OTEC plants; and support universities to perform fundamental research on selected OTEC-related phenomena.

Approach/Background:

PICHTR will participate with SERI and Argonne National Laboratory (ANL) in conceptualization and design efforts for developing the net power-producing experiment (NPPE) by (1) becoming familiar with test results of the heat- and mass-transfer scoping test apparatus (HMTSTA), (2) developing the capability to independently run SERI/ANL system codes and continue the development of analytical codes, (3) providing analytical support to the final design and development of the heat- and mass-transfer experimental apparatus (HMTEA), (4) providing analytical and design support for selecting ancillary systems for the NPPE, and (5) providing for the engineering development of a Phase I turbine conceptual design using existing hardware.

The PICHTR program will continue to support universities in developing fundamental knowledge related to OC-OTEC processes.

Status/FY 1988 Accomplishments:

Began studies of a potential candidate for NPPE turbines, focusing on the possibilities of adapting existing hardware for application to the unique needs of the OC-OTEC process. Identified four potential turbine candidates for further investigation.

Completed a study to incorporate a subroutine into the OC-OTEC system performance model to allow development and evaluation of the production of desalinated water (as a by-product to electricity production).

Completed a study of an intermediate-sized OC-OTEC plant (2-15 MW_e) that combines desalinated water and power production. The analysis compared the cost and performance of various combinations of OC-OTEC subsystems. Also reviewed the SERI

preliminary conceptual design configuration for the 165-kW_e (gross) NPPE OC-OTEC system and recommended modifications.

Began studies at the University of Hawaii to assess noncondensable gas dynamics in OC-OTEC systems and to characterize the fluid dynamics and mass transfer in spout evaporators.

Major Project Reports:

- Matsunaga, K., L. Neill, and A. Bhargava, Sept. 1988, *Computer Model for OC-OTEC Desalinated Water Storage and Transfer System*, draft summary report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

- Bhargava, A., L. Neill, K. Matsunaga, and R. Davis, Dec. 1988, *OC-OTEC System Conceptual Definition*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

- Pacific International Center for High Technology Research, Dec. 1988, *Review of the Conceptual Design for a 165 kW (Gross) OC-OTEC Plant*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

Summary Date: December 1988

Pacific International Center for High Technology Research (PICHTR)—Experimental Support

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: A. Trenka

Telephone: (303) 231-1866

Contractor:
Pacific International Center for
High Technology Research
2875 South King Street
Honolulu, HI 96826

Principal Investigator: L. Vega

Telephone: (808) 945-7635

Contract Number: XX-8-07206-1

Current Contract Period:
From: 01/15/88 **To:** 07/15/89

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	-0-	—
FY 1988	$115,000	DOE

Objective:

To provide technical support to the subsystem and system tests of hybrid and open-cycle OTEC (OC-OTEC) configurations in seawater.

Approach/Background:

Provide engineering support to PICHTR for operation and testing activities for the heat- and mass-transfer scoping test apparatus (HMTSTA) at the Seacoast Test Facility (STF). Also provide PICHTR with engineering design and planning support for modifying and fabricating HMTSTA hardware in preparation for future seawater tests of such components as a hybrid-cycle system and OC-OTEC components at the STF.

Status/FY 1988 Accomplishments:

Began field and experimental support from PICHTR in September 1988 at the STF. Assigned a full-time test engineer from PICHTR to help operate the HMTSTA and conduct tests. PICHTR will assume operation of the facility in December 1988.

Major Project Report:

- Link, H., Nov. 1988, *The Safe Operating Procedure (SOP) for the HMTSTA Phase I and Phase II*, SERI internal report, Golden, CO: Solar Energy Research Institute.

Summary Date: December 1988

Pacific International Center for High Technology Research (PICHTR)—Seawater System Analysis

Project/Area/Task:
Materials and Structures Research

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, CO 80401

Project Manager: A. Trenka

Telephone: (303) 231-1866

Contractor:
Pacific International Center for
High Technology Research
2875 South King Street
Honolulu, HI 96826

Principal Investigator: L. Vega

Telephone: (808) 945-7635

Contract Number: XX-8-07206-1

Current Contract Period:
From: 01/15/88 **To:** 07/15/89

Contract Funding:		Source:
FY 1986	$500,000*	DOE
FY 1987	$65,000	DOE
FY 1988	$50,000	DOE

Objectives:

To estimate the costs of various seawater supply system options for small, shore-based OTEC plants and assess the risks involved in pursuing each option; to provide support for the seawater supply system upgrade at the Natural Energy Laboratory of Hawaii's (NELH) Seacoast Test Facility (STF); to identify technical unknowns of various system options for small, shore-based OTEC plants and assess the risks involved in pursuing each option; and to develop a long-range resource and development plan for the seawater supply system.

Approach/Background:

Continue the cost and risk analyses of system configurations determined to be the most promising based on the Seawater Supply Systems Workshop held in April 1988. Develop a set of recommendations for future system work and a long-range research and development plan for a seawater supply system designed to achieve the DOE cost goals for open-cycle OTEC systems.

Status/FY 1988 Accomplishments:

Completed upgrade of the STF in FY 1988. The seawater supply system, a cooperative project of DOE and the state of Hawaii and supported by PICHTR, substantially increased the flow rates of the warm and cold seawater available at the STF.

Held the Seawater Supply Systems Workshop, which resulted in a technical report describing the cold-water pipe (CWP) options studied and the associated materials and deployment techniques. Concluded that no CWP construction and installation techniques currently approach the DOE cost goals in the 10-17 ft diameter (5-15 MW_e) size range for off-shore pipe sections. Identified drilling and tunneling as a viable option in areas where the geology is appropriate.

Recommended research on analytical, materials, and process issues that must be resolved to make valid evaluations of the options.

Major Project Reports:

- Lewis, L.F., J. Van Ryzin, and L. Vega, 1988, "Steep Slope Seawater Supply Pipeline," *Proceedings, American Society of Civil Engineers' 21st International Conference on Coastal Engineering*, Costa del Sol-Malaga, Spain, June 20-25.

*See "Seacoast Test Facility Seawater Supply System Upgrade" contract description under U.S. Department of Energy section.

- Nihous, G., and L. Vega, Oct. 1988, *Bottom-Mounted OTEC Seawater System Workshop Summary Report*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

- State of Hawaii, 1986, "HOST Park, First Increment and Seacoast Test Facility Upgrade, Keahole, North Kona, Hawaii," Job 81-26-8018, Plans and Specifications, Honolulu, HI: Department of Accounting and General Services, State of Hawaii.

Summary Date: December 1988

Argonne National Laboratory

Hybrid Cycle System Analysis and Integration

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: M. Kim

Telephone: (202) 586-6262

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number: 495-18

Current Contract Period:
From: 01/03/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$195,000	DOE
FY 1988	$70,000	DOE

Objectives:

To develop a methodology and data base for hybrid-cycle system analysis and to optimize the engineering concepts on a cost/performance basis.

Approach/Background:

Define integrated hybrid-cycle OTEC systems for simultaneous production of electric power and desalinated water. Develop performance models for system components. Develop a personal-computer-based program for determining the overall performance. Analyze component integration and performance.

Status/FY 1988 Accomplishments:

Task was continued from FY 1987. Developed a personal-computer-based program for system performance. Developed a concept for integrating components to minimize intercomponent losses and to reduce costs. Analysis shows that the ratio of power to water can be varied without significant penalty. Analyzed the air-removal subsystem in detail and evaluated various compressors. Identified the plate-and-fin heat exchanger as the most suitable candidate for intercoolers. Components required for the air-removal system are available, but their integration requires a one-of-a-kind design.

Major Project Reports:

- Panchal, C.B., and K.J. Bell, 1987, "Simultaneous Production of Desalinated Water and Power Using a Hybrid-Cycle OTEC Plant," *Journal of Solar Energy Engineering*, Vol. 109.
- Rabas, T.J, C.B. Panchal, and H.C. Stevens, 1989, "Integration and Optimization of the Gas Removal System for Hybrid-Cycle OTEC Power Plants," to be presented at the ASME International Solar Energy Conference, April 1989, San Diego, CA.

Summary Date: December 1988

Experiment Planning for Hybrid-Cycle OTEC

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: M. Kim

Telephone: (202) 586-6262

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number: 495-18

Current Contract Period:
From: 01/03/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$33,000	DOE
FY 1988	$30,000	DOE

Objective:

To develop a plan for the experimental verification of critical components of the hybrid-cycle power system.

Approach/Background:

Identify critical components that could have major impacts on the hybrid-cycle system. Integration of seawater evaporation, steam condensation, and ammonia evaporation creates uncertainties in performance predictions. Evaluate an alternative seawater flash-evaporation configuration more suited for the hybrid- cycle power system. Use the heat- and mass-transfer scoping test apparatus (HMTSTA) for component testing at the subsystem level for experimental verification of performance.

Status/FY 1988 Accomplishments:

Determined that HMTSTA is suitable for conducting hybrid-cycle experiments. Developed a concept for a modular system that can be easily integrated into the HMTSTA. The major component to be tested is the steam condenser/ammonia evaporator with an attached vent condenser. Evaluated modifications and additions to the existing HMTSTA configuration. Prepared sketches that can be used to generate engineering drawings and initial cost estimates.

Major Project Report:

- Panchal, C.B., T.J. Rabas, and L.E. Genens, 1989, *Experimental Program Planning for Hybrid-Cycle Component Performance Testing and Verification Using HMTSTA*, ANL internal report (in preparation).

Summary Date: December 1988

Open-Cycle Heat and Mass Transfer in Surface Condenser

Project/Area/Task:
Thermodynamic Research and Analysis

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: C. Castellano

Telephone: (202) 586-6265

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number:
85493 (FY 1986) SERI
495-18

Current Contract Period:
From: 01/03/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	$69,000	SERI
FY 1987	$195,000	DOE
FY 1988	$195,000	DOE

Objectives:

To investigate the effects of noncondensable gases on the rate of condensation in open-cycle OTEC surface condensers and to develop a performance model and design criteria for the condenser.

Approach/Background:

Develop performance-prediction methods that take into account local effects of noncondensable gases. Analyze subsystems to determine the most suitable configuration. Use data from the heat- and mass-transfer scoping test apparatus (HMTSTA) to refine the prediction methods. Develop specifications for a test unit with prototypical flow configuration. Use experimental data from the test unit to verify the prediction methods. Develop design criteria for the condenser for OTEC applications.

Status/FY 1988 Accomplishments:

Developed performance-prediction methods for the cross-flow configuration. Conducted analysis to determine performance under OTEC conditions. Prepared a test plan for stages 1 and 2 condensers installed at HMTSTA. Compared data with predictions. Conducted performance analysis for test units having 1, 2, and 3 water passes. Prepared geometry specifications.

Major Project Reports:

- Panchal, C.B., and K.J. Bell, 1984, "Theoretical Analysis of Condensation in the Presence of Noncondensible Gases as Applied to Open-Cycle OTEC Condensers," *Proceedings, American Society of Mechanical Engineers 1984 Winter Annual Meeting*, New Orleans, LA; ASME Paper 84-WA/Sol-72.
- Panchal, C.B., May 1986, *Study of Noncondensible Gases in Open-Cycle OTEC Surface Condensers*, interim Argonne report submitted to SERI.

Summary Date: December 1988

Design and Implementation of Heat- and Mass-Transfer Scoping Test Apparatus (HMTSTA)

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: C. Castellano

Telephone: (202) 586-6265

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number:
495-16 ($386K)
495-18 ($24K)

Current Contract Period:
From: 02/18/87 **To:** 09/30/88

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$250,000	DOE/SERI
FY 1988	$160,000	DOE/SERI

Objectives:

To design and install the heat- and mass-transfer scoping test apparatus (HMTSTA), Phases I and II.

Approach/Background:

Complete HMTSTA design at Argonne and install HMTSTA at the Natural Energy Laboratory of Hawaii based on design criteria established by SERI. Provide technical labor and other support for installation of major equipment and instrumentation. Provide technical assistance for checkout operation, and complete acceptance tests.

Status/FY 1988 Accomplishments:

Completed HMTSTA installation with Phase I surface condenser in July 1987 and produced first desalinated water shortly thereafter. Completed installation of the Phase II direct-contact condenser in 1988. Modified three 1-MW_t heat exchangers used previously in another DOE program for this program. Provided staff and technician support for installation and checkout of the entire facility.

Major Project Reports:

- Thomas, A., and D.L. Hillis, 1988, "First Production of Potable Water by OTEC and Its Potential Applications," *Proceedings, MTS/IEEE Oceans '88 Conference*, Baltimore, MD, October 31—November 2.

- Panchal, C.B., and H.C. Stevens, 1986, "Apparatus for the Open-Cycle OTEC Heat and Mass Transfer Experiments at the Seacoast Test Facility," *Proceedings, MTS/IEEE Oceans '86 Conference*, Washington, DC, September 23-25.

Summary Date: December 1988

Analysis of Seawater Biofouling and Corrosion of Materials Test Data

Project/Area/Task:
Materials and Structures Research

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: M. Kim

Telephone: (202) 586-6262

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number:
495-16 (FY 1987)
495-18 (FY 1987-88)

Current Contract Period:
From: 10/01/87 **To:** 09/15/89

Contract Funding:		**Source:**
FY 1986	-0-	—
FY 1987	$129,000	DOE/SERI
FY 1988	$75,000	DOE

Objectives:

To analyze seawater biofouling and corrosion data and prepare a final report.

Approach/Background:

Conclude experiments at the Natural Energy Laboratory of Hawaii (NELH). Collect samples and test sections. Analyze samples for long-term corrosion and fouling film. Document analysis and prepare a final report covering all aluminum experiments at NELH.

Status/FY 1988 Accomplishments:

Concluded all experiments at NELH in FY 1987 as planned. Catalogued remaining sample sections for analysis of weight loss, pitting corrosion, fouling film structure, and abnormal corrosion behavior. Prepared an interim report for qualification of aluminum for OTEC applications. Prepared an outline for the final report and completed a section on uniform corrosion. Compiled all corrosion and fouling data on a personal-computer-based computer system. Completed analysis of final samples drawn from NELH; the University of Hawaii began preparation of a final report.

Major Project Reports:

- Stevens, H., May 1988, *Qualification of Aluminum for OTEC Heat Exchangers*, interim ANL report, Argonne, IL: ANL.
- Panchal, C.B., May 1987, "Experimental Investigation of Marine Biofouling and Corrosion for Tropical Seawater," *Proceedings, NATO Workshop on Advances in Fouling Science and Technology*, Algarve, Portugal.
- Sullivan, P.K., August 1988, *OTEC Heat Exchanger Materials Testing Analysis of Samples Exposed at Keahole Point, Hawaii, 1982-1987*, draft report submitted to ANL, Honolulu, HI: Oceanit Laboratories, Inc.

Summary Date: December 1988

Surface Condenser Experiments

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: C. Castellano

Telephone: (202) 586-6265

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number: 495-18 (FY 1986)

Current Contract Period:
From: 02/18/87 **To:** 12/15/87

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	-0-	—
FY 1988	$130,000	DOE

Objective:

To carry out surface-condenser experiments using the heat- and mass-transfer scoping test apparatus (HMTSTA).

Approach/Background:

Develop specifications for surface-condenser test units. Provide technical support for conducting surface-condenser experiments at HMTSTA. Install instruments, troubleshooting at system and subsystem levels, and begin analysis to qualify the data. Coordinate experimental effort with the SERI operator stationed at the test site in Hawaii, including preparing the test schedule. Prepare the test plan for conducting surface-condenser experiments.

Status/FY 1988 Accomplishments:

Prepared a surface-condenser test plan and incorporated it into the overall SERI plan. Furnished staff, technician labor, and other technical support at the site for HMTSTA instrumentation, installation, and calibration. Provided necessary on-site supervision during initial experiments. Completed most planned experiments with the stage 1 condenser. Due to control problems, did not fully complete the stage 2 experiments. Initial analysis of data from the stage 1 condenser indicated that the performance was close to the original predictions and that the venting system designed for the condenser worked efficiently.

Major Project Reports:

- Panchal, C.B., and K.J. Bell, 1987, "Simultaneous Production of Desalinated Water and Power Using a Hybrid-Cycle OTEC Plant," *Journal of Solar Energy Engineering*, Vol. 109.

Summary Date: December 1988

Comparisons of 5-15-MW_e Cold Water Pipe Options

Project/Area/Task:
Materials and Structures Research

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: L. Lewis

Telephone: (202) 586-6265

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number: 495-16

Current Contract Period:
From: 05/11/87 **To:** 06/15/88

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$33,000	DOE/SERI
FY 1988	-0-	—

Objectives:

To assemble cost data on a baseline OTEC seawater system in support of small land-based plants and optimize the design to achieve minimum cost.

Approach/Background:

Assemble cost data using existing information on the 40-MW_e DOE-sponsored pilot plant design, on other earlier shore-based plant designs, and on the adaptation of the inverse-catenary pipe concept used with success at the Natural Energy Laboratory of Hawaii facility. Optimize other components of the seawater systems: the warm-water intake, the warm and cold seawater discharges, and the plant structural and hydraulic aspects. Develop a reference design.

Status/FY 1988 Accomplishments:

Prepared material and attended the OTEC Seawater Systems Workshop in March of 1988 to present "OTEC Land-Based Plant Seawater-System Design Basis." Made additional progress in refining seawater system cost algorithms for cost optimization studies.

Major Project Report:

- Nihous, G., and L. Vega, October 1988, *Bottom-Mounted OTEC Seawater System Workshop Summary Report*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

Summary Date: December 1988

Experimental Equipment for Heat- and Mass-Transfer Scoping Test Apparatus (HMTSTA) Phases I and II

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
Solar Energy Research Institute
1617 Cole Boulevard
Golden, Colorado 80401

Project Manager: A. Trenka

Telephone: (303) 231-1866

Contractor:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

Principal Investigator: A. Thomas

Telephone: (312) 972-8071

Contract Number: 85526

Current Contract Period:
From: 11/07/86 **To:** 05/01/88

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$134,000	SERI
FY 1988	$61,000	SERI

Objective:

To provide equipment and experimental components for the HMTSTA, Phases I and II, facilities assembled at the Natural Energy Laboratory of Hawaii site.

Approach/Background:

Design equipment and experimental components for HMTSTA, Phases I and II, to meet specifications. Rework heat-transfer equipment used in previous DOE OTEC program experiments to minimize cost. The Phase I apparatus met all the requirements of the acceptance test. Design all Phase I components (except the surface condenser) to meet Phase II requirements.

Status/FY 1988 Accomplishments:

Incorporated Phase II equipment (designed and assembled at Argonne National Laboratory) into the HMTSTA after completing Phase I experiments in FY 1988. Completed the Phase II scoping test apparatus in FY 1988. Phase II included designing, assembling, shipping, and installing the direct-contact condenser into the HMTSTA apparatus, along with the necessary facility modifications.

Major Project Reports: None.

Summary Date: December 1988

Single Channel Studies of Noncondensables in Surface Condensers

Project/Area/Task:
Experimental Verification and Testing

Directing Organization:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Project Manager: A. Thomas

Telephone: (312) 972-8071

Contractor:
Florida A&M University
Florida State University
College of Engineering
Tallahassee, Florida 32316-2175

Principal Investigator: J. Tellote

Telephone: (904) 487-6168

Contract Number: 70142401

Current Contract Period:
From: 01/26/87 **To:** 09/30/89

Contract Funding:		Source:
FY 1986	-0-	—
FY 1987	$77,500	ANL
FY 1988	$7,991	ANL

Objectives:

To conduct an experimental investigation of the effects of noncondensable gases on local heat and mass transfer for flow inside a channel and develop a basic understanding of fundamental processes.

Approach/Background:

Prepare an apparatus for conducting single-channel experiments, conduct the experiments, and analyze the data. Project is supported by funds set aside for the Historically Black Colleges and Universities Program and is assigned to Florida A&M University (FAMU) with assistance from Florida State University both at Tallahassee under supervision from Argonne National Laboratory (ANL).

Status/FY 1988 Accomplishments:

As part of the Phase I activity, completed design and acquired all necessary components. Installed two major components—the vacuum pump and the chiller. Prepared the data acquisition system and tested it with selected sensor input. The apparatus is scheduled to be ready for experiments in March 1989. One graduate and two undergraduate (minority) students are scheduled to work on this project. ANL has prepared a test matrix to be developed by FAMU into a detailed test plan.

Major Project Reports: None.

Summary Date: December 1988

U.S. Department of Energy

Seacoast Test Facility (STF) Seawater Supply System Upgrade*

Project/Area/Task:
Materials and Structures Research

Directing Organization:
U.S. Department of Energy
Wind/Ocean Technologies Division
1000 Independence Avenue, S.W.
Washington, DC 20585

Project Manager: L. Lewis

Telephone: (202) 586-6263

Contractor:
State of Hawaii
Department of Business and
Economic Development
Honolulu, HI 96804

Principal Investigator: R. Ulveling

Telephone: (808) 548-4150

Contract Number: DE-FC02-86CH10297

Current Contract Period:
From: 05/30/86 **To:** 01/01/89

Contract Funding:**		Source:
FY 1986	$2,500,000	DOE
FY 1987	-0-	—
FY 1988	$206,000	DOE

Objective:

To provide an upgraded environment for conducting experiments to verify OTEC component functional feasibility and operational characteristics.

*See "Pacific International Center for High Technology Research (PICHTR)—Seawater System Analysis" contract description under Solar Energy Research Institute section.

**Cost is shared with state of Hawaii ($5.6 million) and PICHTR ($0.5 million).

Approach/Background:

Construct and install an expanded seawater supply system at the STF at the Natural Energy Laboratory of Hawaii (NELH). Seawater system supplies warm and cold seawater to support the development of a net power-producing open-cycle OTEC system (at approximately the 165-kW_e gross level). It also supports warm- and cold-water mariculture development at NELH and the adjacent Hawaii Ocean Science and Technology (HOST) Park. This is a cost-shared project with contributions from the state of Hawaii, DOE, and PICHTR.

Status/FY 1988 Accomplishments:

Initiated fabrication, assembly, and deployment of the ocean portion of the seawater system in late 1987 based on design plans developed in 1986. Scheduled site preparation and deployment activities to avoid the Kona storm season and the winter mammal migration period. Installed surf zone and onshore components of the seawater system by mid-1988 and successfully completed a full set of acceptance tests, including operation of all seawater pumps. Worked on the design of a shallow discharge trench.

The seawater system includes high-density polyethylene pipes capable of transporting at least 840 L/s (410 L/s for OTEC experiments) of cold seawater from an approximately 670 m depth; at least 600 L/s of warm seawater from an approximately 20 m depth; and, at least 1010 L/s of seawater from the proposed NELH test area to a discharge structure. The cold-water pipe represents the longest (2060 m) large-diameter pipe traversing the steepest slope ever spanned.

Major Project Reports:

- State of Hawaii, 1986, "HOST Park, First Increment and Seacoast Test Facility Upgrade, Keahole, North Kona, Hawaii," Job 81-26-8018, Plans and Specifications, Department of Accounting and General Services, State of Hawaii, Honolulu, HI.

- Lewis, L.F., L. Trimble, and J. Bowers, 1987, "Open-Cycle Seawater Experiments in Hawaii," *Proceedings, MTS/IEEE Oceans '87 Conference*, Halifax, Nova Scotia, Canada, September 28—October 1.

- Lewis, L.F., J.R. Van Ryzin, and L. Vega, 1988, "Steep Slope Seawater Supply Pipeline," *Proceedings, American Society of Civil Engineers 21st International Conference on Coastal Engineering*, Costa del Sol-Malaga, Spain, June 20-25, 1988.

Summary Date: December 1988

Current Publications

Solar Energy Research Institute

Bharathan, D., July 1988, "Progress in the Claude-Cycle OTEC Research," SERI/TP-253-3379, Golden, CO: Solar Energy Research Institute. Presented at the American Society of Mechanical Engineers Conference on Offshore Mechanics and Arctic Engineering (OMAE Europe '89), The Hague, The Netherlands, March 19–23, 1989.

Bharathan, D., and H. Link, 1988, "Preliminary Results of Seawater Evaporation in Single and Multiple Spouts," SERI draft letter report sent July 29, Golden, CO: Solar Energy Research Institute.

Bharathan, D., B.K. Parsons, and J.A. Althof, Oct. 1988, *Direct Contact Condensers for Open-Cycle OTEC Applications*, SERI/TR-252-3108, Golden, CO: Solar Energy Research Institute.

Bhargava, A., L. Neill, K. Matsunaga, and R. Davis, Dec. 1988, *OC-OTEC System Conceptual Definition*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

Carmichael, A.D., and T.R. Brehm, Sept. 1988, *OTEC Open Cycle Turbine: Innovative Design for Cost Reduction*, report no. 88-5, Cambridge, MA: Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge, MA.

Kreith, F., and D. Bharathan, Feb. 1988, "Heat Transfer Research for Ocean Thermal Energy Conversion," *Journal of Heat Transfer*, Vol. 110: pp. 5–22. 1986 Max Jacob Memorial Award Lecture presented at the ASME/JSME Thermal Engineering Joint Conference, Honolulu, Hawaii, March 22–27, 1987.

Link, H., 1988, *The Safe Operating Procedure (SOP) for the HMTSTA Phase I and Phase II*, SERI internal report, Golden, CO: Solar Energy Research Institute.

Matsunaga, K., L. Neill, and A. Bhargava, Sept. 1988, *Computer Model for OC-OTEC Desalinated Water Storage and Transfer System*, draft summary report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

Nihous, G., and L. Vega, Oct. 1988, *Bottom-Mounted OTEC Seawater System Workshop Summary Report*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

OTEC Group, Apr. 1988, *Ocean Thermal Energy Conversion (Turbine Design)*, Philadelphia, PA: Department of Mechanical Engineering, University of Pennsylvania.

Pacific International Center for High Technology Research, Dec. 1988, *Review of the Conceptual Design for a 165-kW (Gross) OC-OTEC Plant*, draft report submitted to SERI, Honolulu, HI: PICHTR.

Pesaran, A.A., and H. Link, Oct. 1988, "Preliminary Surface Seawater Deaeration Results under OC-OTEC Conditions," SERI draft letter report, Golden, CO: Solar Energy Research Institute.

Schobeiri, I.T., 1988, *Optimum Design of a Low Pressure, Double Inflow, Radial Steam Turbine for Open Cycle Ocean Thermal Energy Conversion*, College Station, TX: Department of Mechanical Engineering, Texas A&M University.

Trenka, A.R., A. Thomas, and L. Vega, 1988, "Technical Developments of OTEC Systems," *Proceedings, International Renewable Energy Conference*, Honolulu, HI, September 18–24.

Valenzuela, J.A., T. Jasinski, W. Stacey, B. Patel, and F. Dolan, June 1988, *Design and Cost Study of Critical OC-OTEC Plant Components*, SERI/STR-22-3246, Golden, CO: Solar Energy Research Institute.

Argonne National Laboratory

Nihous, G., and L. Vega, Oct. 1988, *Bottom-Mounted OTEC Seawater System Workshop Summary Report*, draft report submitted to SERI, Honolulu, HI: Pacific International Center for High Technology Research.

Panchal, C.B., 1987, "Experimental Investigation of Marine Biofouling and Corrosion for Tropical Seawater," *Proceedings, NATO Workshop on Advances in Fouling Science and Technology*, Algarve, Portugal, May.

Panchal, C.B., May 1986, "Study of Noncondensible Gases in Open-Cycle OTEC Surface Condensers," interim report submitted to SERI, Argonne, IL: Argonne National Laboratory.

Panchal, C.B., and K.J. Bell, 1987, "Simultaneous Production of Desalinated Water and Power Using a Hybrid-Cycle OTEC Plant," *Journal of Solar Energy Engineering*, Vol. 109.

Panchal, C.B., and K.J. Bell, 1987, "Theoretical Analysis of Condensation in the Presence of Noncondensible Gases as Applied to Open-Cycle OTEC Condensers," *Proceedings, American Society of Mechanical Engineers 1984 Winter Annual Meeting*, ASME Paper 84-WA/Sol-72, New Orleans, LA.

Panchal, C.B., T.J. Rabas, and L.E. Genens, 1988, *Experimental Program Planning for Hybrid-Cycle Component Performance Testing and Verification Using HMTSTA*, internal report, Argonne, IL: Argonne National Laboratory, forthcoming.

Panchal, C.B., and H.C. Stevens, 1986, "Apparatus for the Open-Cycle OTEC Heat and Mass Transfer Experiments at the Seacoast Test Facility," *Proceedings, MTS/IEEE Oceans '86 Conference*, Washington, DC, September 23–25.

Rabas, T.J, C.B. Panchal, and H.C. Stevens, 1988, "Integration and Optimization of the Gas Removal System for Hybrid-Cycle OTEC Power Plants," to be presented at the ASME International Solar Energy Conference, San Diego, CA, April 1989.

Stevens, H., May 1988, *Qualification of Aluminum for OTEC Heat Exchangers*, interim report, Argonne, IL: Argonne National Laboratory.

Sullivan, P.K., Aug. 1988, *OTEC Heat Exchanger Materials Testing Analysis of Samples Exposed at Keahole Point, Hawaii,*

1982-1987, draft report submitted to ANL, Honolulu, HI: Oceanit Laboratories, Inc.

Thomas, A., and D.L. Hillis, 1988, "First Production of Potable Water by OTEC and Its Potential Applications," *Proceedings, MTS/IEEE Oceans '88 Conference*, Baltimore, MD, October 31–November 2.

U.S. Department of Energy

Lewis, L.F., L. Trimble, and J. Bowers, 1987, "Open-Cycle Seawater Experiments in Hawaii," *Proceedings, MTS/IEEE Oceans '87 Conference*, Halifax, Nova Scotia, Canada, September 28–October 1.

Lewis, L.F., J. Van Ryzin, and L. Vega, 1988, "Steep Slope Seawater Supply Pipeline," *Proceedings, American Society of Civil Engineers' 21st International Conference on Coastal Engineering*, Costa del Sol-Malaga, Spain, June 20–25.

State of Hawaii, 1986, "HOST Park, First Increment and Seacoast Test Facility Upgrade, Keahole, North Kona, Hawaii," Job 81-26-8018, Plans and Specifications, Honolulu, HI: Department of Accounting and General Services.

Index of Current Contractors

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