The U.S. Department of Energy Ocean Energy Technology (DOE/OET) Program was instituted to develop options for extracting and distributing significant amounts of ocean energy in a reliable, environmentally acceptable and cost-effective manner. Since its inception in 1974, the program originally emphasized the identification of the most viable ocean energy options and determination of their resource potential. Ocean current devices, wave energy extraction techniques and ocean thermal energy conversion (OTEC) systems were investigated. Because the OTEC projected energy extraction potential is one to two orders of magnitude greater than the other ocean energy options, 90% of ocean energy funding has gone to this area. The DOE role is in technology development and basic and applied research. Generally, engineering development activities fall within the domain of private industry.

Both wave and current devices extract kinetic energy from the ocean using a variety of methods. Ocean thermal conversion uses the difference in temperature between surface waters heated by the sun and colder deep (up to 3000 feet) ocean waters. These two sinks provide a temperature difference of about 20°C in ocean areas between ±20° of the equator. There are two power cycles under development in OTEC: open cycle and closed cycle. Open cycle uses sea water as the working fluid and closed cycle uses ammonia or freon as the working fluid in a closed loop.

The summary of OET Program activities during the period FY 1980 through FY 1983 represents the more significant findings of DOE-sponsored research and development in each of six program elements: Advanced Power Systems Development, Closed-Cycle Power Systems Development, Alternative Energy Systems Development, Environmental Research, Ocean Engineering, and Engineering Development. Although the FY 1984 program is still being formulated, twenty of the areas of uncertainty remaining to be resolved are listed and indicate the thrust of present planning.

ADVANCED POWER SYSTEMS DEVELOPMENT PROGRAM ELEMENT

The Advanced Power Systems work concentrates primarily on open-cycle research.

Two types of innovative OC-OTEC systems with the potential for supplying significant amounts of usable energy have been identified: the open rankine cycle (often called the Claude cycle after its inventor) and a more recent innovation referred to as the two-phase lift cycle. In the Claude cycle, warm tropical seawater is flash evaporated in a vacuum chamber to produce low density steam which then is passed through a large, low pressure turbine to produce electrical power. Cold seawater, pumped from the deep ocean, is used to condense the steam and complete the cycle. Condensation may be accomplished through direct contact of the steam and cold seawater or by surface condensation using conventional shell and tube heat exchangers. The surface condenser option has the added benefit of producing fresh water as a by-product. During these processes, dissolved non-condensable gases evolve from the sea-water which must be exhausted from the condenser in order to maintain system pressure and thermal cycle heat transfer efficiency. A portion of the produced power is used to compress and expel these gases. Alternatively, the seawater may be deaerated (i.e., removal of non-condensable gases) before entering the direct contact heat exchangers. Additional seawater pumping power is associated with this option. A demister for separating entrained seawater droplets from the steam generated in the evaporator may be required in some systems to prevent corrosion and contamination of the fresh water by-product.

The two-phase lift cycle produces electricity by running warm seawater through a hydraulic turbine located at the bottom of a sub-merged vertical pipe. A two-phase generator then produces a mixture of steam and seawater at the bottom of a large, evacuated, lift tube. The high velocity steam carries the liquid through shear forces back to sea level where cold seawater condenses the steam in a direct contact heat exchanger. Two types of mist and foam mechanisms have been studied. The mist generator is an array of nozzles which produces a fine seawater spray. The warm droplets instantaneously evaporate to produce high velocity steam. By adding a surfactant to the two-phase mixture a foam structure develops. The vapor and liquid are closely coupled reducing friction losses and allowing the process to proceed near thermodynamic equilibrium. These advantages are offset by the added cost and environmental impact of the surfactant and the possibility that anti-foaming chemicals may be needed at the condenser. Research on lift cycles has concentrated on the thermal and fluid dynamics where many uncertainties exist.

The most important Claude cycle technical uncertainty identified was the performance of direct contact heat exchangers operating at typical OTEC boundary conditions. Experiments were completed on several flash evaporator geometries, including open channel trays, falling films, various configurations of falling jets and vertical spouts. Vertical spout geometries demonstrated best thermal performance, low liquid head losses, reduced platform area requirements, and a significant improvement over the original open channel tray concept. Most Claude cycle designs use a surface condenser since their performance is well understood. However, the potential of direct contact condensers is significant and research on the effects of non-condensable gas concentration, as well as steam and water flow rates on their effectiveness, have been initiated. As the warm seawater rises in the intake pipes, the pressure decreases to the point where gas begins to evolve. If a significant amount of gas comes out of solution, designing a gas trap before direct contact, heat exchangers may be justified. Experiments simulating conditions in the warm water intake pipe indicated about 30% of the dissolved gas evolved in the top 8.5m of the tube. The tradeoff between preazeotroisation of the seawater vs. expulsion of all the non-condensable gases from the condenser is dependent on gas evolution dynamics, deaerator efficiency, head loss, vent compressor efficiency and parasitic power. Work is in progress on optimization of vertical spout condenser geometries. Results to date show vertical spouts improve condenser performance by approximately 30% over falling jet configurations. Another approach for reducing exhaust compressor parasitic power in vertical spout evaporators is being investigated. After most of the steam has been condensed by spout condensers, the non-condensable gas-steam mixture is passed through a counter-current region which increases the gas-steam ratio by a factor of five. The result is an 80% reduction in the exhaust pumping power requirements.

Exploratory research on large diameter, low pressure turbines was performed during FY 80-81. Analytical tools for evaluating aerodynamic and structural characteristics were developed and used to define the blade profile for a 141MW e turbine. A materials assessment found that properly oriented E-glass filaments with epoxy resin provided sufficient blade structural strength. Diurnal and seasonal changes in the warm and cold seawater temperatures affect the available enthalpy drop across the turbine and the steam mass flow rate. A computer routine developed to predict the off-design performance of the turbine showed that the efficiency is lowered by only 2% for a drop of seawater inlet temperature of 5°C.

Five commercially available demisters were tested with the vertical spout evaporator. Four were constructed of woven wire mesh and one was a parallel channel Chevron demister. The pressure drop through the demisters for a variety of steam velocities was measured. The lowest pressure drop was obtained with the Chevron demister. Visual observations showed that entrainment of captured liquid occurred at steam velocities of 30 m/s with the Chevron demister.
High steam velocity significantly decreases the required demister cross sectional area which, in turn, impacts the total plant area and cost.

Several analytical models of the mist lift process were developed. Two steady-state computer algorithms calculated the maximum achievable lift height for various drop sizes, flashdown temperatures and warm seawater inlet mass flow rates. Including provisions for droplet coalescence and breakup reduced the predicted maximum lift height, but the degradation was better than predicted by models which only account for droplet coalescence. A maximum droplet size of about 0.5 mm was predicted and "rainout" of large droplets was not a major problem. A transient model was developed to examine the stability of the process when evaporator and condenser conditions change with time. Results indicated the lift process is stable when operated within reasonable bounds.

Several small scale test columns were constructed to investigate the two-phase flow of OTEC mist and foam lift cycles. Results were obtained from a 3.7 mm high mist lift experiment which examined the effects of fluid injection velocity and vapor-fluid slip, and led to expansion of the test program to include tests using seawater. Plans for further tests, including a larger lift tube and various liquid injector geometries, are being formulated.

Closed-Cycle Power Systems Development Program Element

The Closed-Cycle Power Systems Development Program was instituted in response to a need to develop low-temperature difference heat exchangers. The performance of these components and associated biofouling and corrosion are the major areas of investigations.

The heat exchanger effort has used two facilities to test advanced designs and configurations. A laboratory test facility was constructed at Argonne National Laboratory and has been used to obtain performance data on 13 heat exchangers provided by industrial and university designers. The 25KWe facility has separate loops for warm water, cold water, and the working fluid.

The OTEC-1 was a converted T2 tanker and was designed to test heat exchangers for 1MWe plants under actual ocean conditions. Plain and enhanced evaporator tubes as well as plain condenser tubes in a 1MWe shell and tube configuration were tested. While the plain-tube bundle evaporator performed as predicted under static conditions, the enhanced-tube bundle evaporator did not. This was apparently due to fouling of the high flux surface. Performance of the condenser tested was in agreement with predictions based on single-component (water) flow in the tubes. The evaporator, configured to represent one quadrant of a 4 MWe unit, functioned without excessive droplet entrapment on the interface with the ammonia spray feed. Additionally, evaporator tubes enhanced with a High Flux (nucleation-promoting) surface performed poorly, thus demonstrating the vulnerability of this coating in an open ocean environment. The motion of the ship did not affect the performance of the heat exchangers. Liberation of dissolved gases in the cold water did not affect condenser performance.

The results from the heat exchanger testing effort have been significant. Heat exchanger performance has been improved by a factor of 2.5:1 for both evaporators and condensers over SOA plain tube designs. Because contamination of ammonia by water in excess of about 0.1% results in an appreciable degradation of performance, ammonia purification systems are now included in OTEC plant designs. Additionally, it has been shown that the performance of plate-frame evaporators designed originally for liquid-to-liquid service can be improved by a factor of 2 with the addition of nucleation enhancement to the ammonia side aiding in the boiling heat transfer process. Finally, brazed aluminum plate-fin exchangers offer a powerful combination of high performance and low initial cost. At the initiation of the test program, it was projected that heat exchangers would contribute half the cost of an OTEC plant. Current cost estimates are projected to account for 30% of the total plant cost.

As seawater flows through an OTEC heat exchanger, the heat transfer surfaces are fouled by the gradual deposition and growth of colonies of micro-organisms. Uncontrolled biofouling leads to degradation of the heat exchangers' performance and eventual plant shutdown. Furthermore, seawater created corrosion limits component life.

Over the last three years, the program has conducted biofouling and corrosion experiments at: Wrightsville Beach Test Facility (near shore); Punta Tuna, Puerto Rico, Open-Ocean Test Facility; and the Hawaiian Seacoast Test Facility (STF). As part of the research effort, Carnegie-Mellon University (CMU) developed a heat-transfer monitor for circular channels which was later modified for noncircular channels, including those with enhanced heat-transfer promoters on the surfaces. It allows accurate, on-line measurements of the biofouling buildup on heat exchangers. The rate of corrosion of heat exchanger materials is measured using sample units installed in the flow system. The rate of biofouling was found to be comparable for titanium and aluminum surfaces. Biofouling is negligible in the deep, cold seawater environment.

Biofouling buildup can be controlled for several months using brushes, sponge balls or chlorination. Intermittent chlorination (0.05 ppm for 1 hr/day) can keep titanium heat exchanger surfaces sufficiently clean for at least one year. In addition, chlorination can be used to clean already-fouled surfaces. In studies on corrosion and biofouling of aluminum alloy surfaces three basic types of aluminum were tested: a 3004 alloy, with and without cladding containing zinc, a zinc-coated 3003 Alclad alloy, and a 3003 Alclad alloy. Intermittent chlorination is less effective for preventing biofouling on 3003 Alclad than on titanium for near shore water, but equally effective for open ocean water. The rate of corrosion is sensitive to the frequency and intensity of brush or Amerap ball cleaning. While the initial rate of corrosion for the aluminum surface is high, the assumption value is low. The corrosion rate for zinc-coated surfaces was found to be comparable to that of Alclad surfaces.

The Seacoast Test Facility at Keahole Point, Hawaii, has been in operation since June 1981. It is the first permanent land-based OTEC facility built for conducting biofouling, corrosion, biocontrol and other related tests. There are several objectives that the program hopes to achieve at STF during these tests. They include efforts to: (1) develop coating and cladding for aluminum to extend its service life to 25-30 years, (2) develop biofouling control methods for waterside enhanced heat exchanger surfaces and for compact heat exchangers, (3) determine the minimum chlorination required to keep the biofouling resistance below 0.0001 hr$^{-2}$F/Btu (which would represent a heat transfer degradation of about 10% in a high performance heat exchanger), and (4) evaluate alternatives to chlorination as a biofouling control method. Initial experiments used warm seawater, but more recently the first mobile cold water data base has begun to emerge. The present seawater supply systems are temporary and plans for conversion to a more permanent supply are being developed.

Enhanced heat transfer in the cold water heat exchanger on the seawater side through application of ceramics and water mist flow, could reduce plant costs by another 10% but needs to be experimentally verified. Increases in the life expectancy (corrosion, fouling, structural integrity, materials) of low-cost heat exchangers would also have a dramatic cost impact.

Alternative Energy Systems Development Program Element

The alternative energy systems development has centered on plantships and energy intensive products. OTEC plantships would cruise through tropical waters using the thermal gradient to run a heat engine, produce electricity, and synthesize energy-intensive products such as ammonia, hydrogen or methanol. The baseline design for a pilot plantship was completed in FY 78 for a 10-20MWe sized ship and modified in FY 80 to provide for operation in either a cruising o moored plant mode. This design alteration allowed for an increase in the net power capacity from 20MWe to 40MWe. Scale-model tests were conducted to verify the design parameters of the 40MWe plantship components and overall design. The results were matched against computer models of the designs and a 1/30 scale model built and tested.

Since mobility is a major feature of the plantship design, a technique for distribution of power other than electrical cable-to-shore is
required. One approach is the on board production of energy intensive materials such as liquid hydrogen, ammonia, and methanol, or solid aluminum and lithium. Ammonia and methanol were the main products of investigation.

Ammonia is a synthetic fuel that can be readily produced at sea on cruising OTEC plantships, utilizing hydrogen from seawater and oxygen from the air. Hydrogen is freed from the seawater through distillation, deionization, and electrolysis. Ammonia can be used either in fuel cells or as a fuel for other engines. An investigation was performed to determine the feasibility of ammonia OTEC production and its economic feasibility. Results indicated that ammonia may become a viable OTEC commercial product, but is not competitive with ammonia made from natural gas today.

Production of OTEC methanol involves the transport of coal to the plantship. Combustion of the coal on the plantship with electrolytic oxygen then forms carbon monoxide (CO). Finally, a reaction of the CO with electrolytic hydrogen on the plantship forms methanol. Early studies based on liquid CO\textsubscript{2} as the carbon source indicated that the production of methanol on an OTEC plantship by combining CO\textsubscript{2} with the H\textsubscript{2} and O\textsubscript{2} from the electrolyzers, would be more costly than ammonia. However, by using coal as the carbon source, the plant can produce 2 1/2 times as much methanol as ammonia at equal OTEC power capacity. Another advantage of methanol is its compatibility with existing fuel storage and handling systems.

An appraisal of the physical requirements, sizes, and constraints for an OTEC methanol-from-coal plantship was addressed. This resulted in a conceptual design of an OTEC 160MWe plantship producing 1000 metric tons/day of fuel grade methanol. Preliminary analysis indicated that methanol from such a plantship would be marginally competitive with methanol from other sources. The design was based on a Texaco gasifier design using a coal slurry fuel. Several inhibiting features of this process are the presence of excess CO\textsubscript{2}, H\textsubscript{2}S production and large quantities of waste water. A study made, utilizing the Rockwell Molten Carbonate gasifier design which produces a gas relatively free from CO\textsubscript{2} and H\textsubscript{2}S, indicated this gasifier would produce methanol that is economically competitive. The use of coal slurry requires expensive land based water treatment, as well as coal slurry preparation and loading facilities.

ENVIRONMENTAL RESEARCH PROGRAM ELEMENT

The net environmental impacts resulting from OTEC development are expected to be minimal compared to the impacts of fossil fuel and nuclear power production. OTEC development on a commercial basis also can be acceptable if proper attention is paid to design. During FY 80-83, the OTEC Environmental Program has provided baseline information during the exploratory design phases for deepwater closed-cycle OTEC systems to ensure that such designs are survivable and environmentally sound.

In FY 80 the major effort was in field measurements and environmental compliance assessment. In FY 81 the program emphasized the integration of the various test and field studies to ensure uniformity in the data base and completion of the benchmark studies while cooperating with the OTEC-1 tests and insuring permit compliance. During FY 82, efforts were directed towards data analysis, completion of the OTEC-1 benchmark reports and preparation for the marine research and compliance activities associated with the OTEC Pilot Plant. In FY 83, the focus was in support of the Pilot Plant activities including participation in and analysis of the State of Hawaii Common Base Program, and maintenance of the permit compliance schedules. Research activities were limited to the evaluation of bottom assessment strategies and updating an existing computer flow model.

The shift in program emphasis from off-shore deep-water moored to near-shore shallow-water bottom-mounted test plants with long bottom mounted cold water pipes requires new consideration of near-shore and along the bottom environmental design concerns. This suggests more emphasis on marine geology than water column oceanography. Unfortunately, the use of environmental loading parameters, mooring and deployment procedures definition, and instrumentation requirements. Upon completion, a CWP 8 feet in diameter and 400 feet in length was fabricated. The suspended pipe test was conducted by attaching a bottom weighted CWP (20 lb/ft water weight) to a scaled platform barge through a gimbal. Five 80-foot-long pipe segments were joined.

OCEAN ENGINEERING PROGRAM ELEMENT

The Ocean Engineering activities address cold water pipes (CWP), Sea-water Systems (SWS), Moorings/Foundations and Platforms.

The CWP is a major component of all OTEC systems. It has been by far the most difficult engineering challenge addressed by the program because of its unique characteristics, which primarily stem from its size. Typically, 40MWe land-based or shelf-mounted baseline designs require a CWP on the order of 10,000 feet in length and 30 feet in diameter. These dimensions for an underwater structure are unprecedented, and industrial experience in the required fabrication, deployment, installation, inspection, maintenance and repair techniques is lacking. Thus, an extensive research and engineering effort has been pursued in cold water pipes.

In FY 80, the program focused on developing baseline designs and computer model codes for defining and evaluating physical stresses on the CWP. Further development and model testing validated these codes. Numerous CWP concepts were evaluated. Of these concepts, six were selected to enter a baseline design phase. One design, the Fiber-Reinforced Plastics (FRP) sandwich, exhibited the greatest potential for long-term system life expectancy and economic viability. This potential is due to its high strength-to-weight ratio, flexibility, resistance to electrochemical interaction, relative low cost, and ease of deployment. Subsequent work concentrated on FRP materials for cold water pipes.

The basic FRP design is a monolithic cylindrical structure with a sandwich wall composed of two equal thicknesses of FRP laminate material separated by a syntactic foam core. Materials testing efforts were performed on the FRP design to provide engineering data on static and fatigue performance.

Several modeling activities were undertaken to analytically predict the environmental loading and subsequent stresses acting on the CWP. A three-dimensional design methodology was developed around a computer-aided analytical model which provides a time-domain dynamic simulation of the coupled CWP response to hydrodynamic loading of the CWP/Platform/Mooring systems caused by waves and currents. The output of this model is a statistical summary which predicts the interaction of a variety of forces including: CWP/platform motions, hydrodynamic forces, pipe loads and internal pipe stresses.

As part of the validation process, a CWP at-sea model test was performed off the coast of Catalina Island. The model was 1 foot in diameter, 70 feet long and constructed of polyvinyl chloride. Five axial stations along the pipe held instrumentation that measured the structural effects of waves and currents. The CWP was suspended from a '1/30th scale OTEC barge platform and was analyzed in grazing and moored moes. This at-sea test and subsequent analysis supplied insight to the relationship between vortex shedding and CWP structural response. A small-scale CWP tow-out and deployment project model test was performed to validate analytical methods for calculating CWP response during deployment operations. This test utilized numerous scaled CWP models. The maximum size of the models was 1.50 scale for a 30-foot diameter prototype CWP, and ranged to 1:110 scale for turning and swing-down tests. Upon investigating tow stability, resistance, heading limitations, maneuverability, and swing-down loads in afloat, swash and submerged modes, the study concluded horizontal tow-out and swing-down was technically feasible. However, loads experienced during the tow-out procedure, caused by waves and currents directed at high angles, were critical. Improved transportation loads analysis techniques will be required to increase design confidence.

The culmination of these efforts is a three-phased FRP Scaled CWP At-Sea Test Program. The objective is to design, fabricate and test a scaleable FRP CWP in suspended and slope-mounted configurations. The planning and design stage of the project included overall design, analysis of static dynamic loads, laminate design, materials test, determination of environmental loading parameters, mooring and deployment procedures definition, and instrumentation requirements. Upon completion, a CWP 8 feet in diameter and 400 feet in length was fabricated. The suspended pipe test was conducted by attaching a bottom weighted CWP (20 lb/ft water weight) to a scaled platform barge through a gimbal. Five 80-foot-long pipe segments were joined.
The major focus in sea-water systems was to develop an analytical code to predict the performance of the OTEC water loops. This involved development of a dynamic analytical computer model that simulates the performance of the SWS components and parametric sensitivity studies applied to the Johns Hopkins University/Applied Physics Laboratory Grazing Plantship, the Gibbs & Cox Spar Plant, and OTEC-1. Model response predictions were compared to measured data to fine tune the model.

A substantial research effort was performed in the Mooring/Foundations area through FY 82 including a preliminary design analysis of two types of stationkeeping subsystem, the Multiple Anchor Leg (MAL) Mooring System for the OTEC floating barge configuration and the Tension Anchor Leg (TAL) Mooring System for the spar configuration. The MAL consists of catenary-type anchor moorings arranged in pairs at each corner of a barge, whereas the TAL incorporates a solid spar configuration moored with taut lines. In general, TAL appears to be less costly but MAL is closer to SAO and entails less risk. Two assessments of mooring technology were performed to summarize and evaluate the mooring SAO and evaluate the feasibility of using scaling techniques to determine relative forces associated with mooring system/sea environment interactions. It was found that the scaling of mooring systems would not be an accurate procedure if the relative depth of the scaled system to a full-size system was greater than an order of magnitude apart.

An analysis of platform construction techniques was developed with respect to the floating platform configuration. The baseline scenario investigated was a 40 MWe commercial OTEC plant in the ship hull and spar hull configurations. Hull materials evaluated included steel and concrete. The CWP material choices were steel, concrete, FRP, and elastomeric. Three deployment locations were evaluated: Florida west coast, Puerto Rico and Hawaii. Construction requirements were compared with current industrial capabilities. Results were then integrated with the potential deployment locations. In general, the study concluded that present United States industrial capabilities meet the construction requirements for concrete and steel hulls. If segmented construction techniques are applied to the steel hull area, present U.S. facilities are adequate. Facilities for concrete hull construction, are not presently available in the United States. Notably, concrete was deemed to be the most advantageous material for hull construction.

The cable subsystem is a critical development area with respect to the overall feasibility of the moored/ floating OTEC plant configuration. The basic design consists of a long cable suspended in a catenary configuration from the platform and attached to the connector between the plant and the bottom transmission cable. The environmental loading (i.e., waves, currents, and hydrostatic pressure), platform motion, and the weight of the cable itself define the complexity of the design considerations. Additionally, the design must be life cycle cost effective. Two cable designs were developed and evaluated in the OTEC Program. The self-contained cable filler (SCOF) concept used a laminated oil-impregnated paper insulation and the extruded solid insulation design featured cross-linked polyethylene (XLPE). Both cable systems included four single conductor cables (three phases and a spare) capable of carrying of 100 MWe load. The program also addressed the cable terminal component (platform/cable interface), mechanical cable termination, electrical termination, and emergency disconnect. The SCOF was chosen for the OTEC application due to its laminated insulation. Test failures occurring in this design were due to “sleeping,” i.e., relative motion between the cable conductor and the laminated insulation which leads to paper tape slippage and premature cable breakdown. An ideal cable termination scenario, where each cable component is terminated in a plane perpendicular to the cable axis, has been proposed to eliminate the sleeping problem. Until the SCOF cable is tested in this scenario however, its suitability for the OTEC application cannot be determined.

The Engineering Development Program Element involves large experiments such as the OTEC-1 ocean-based engineering test bed and the 40 MWe Pilot Plant Proof-of-Concept. Both efforts were initiated pre-FY 80. The OTEC-1 project fostered a broad spectrum of engineering evaluations on key OTEC components and provided valuable input to all areas within the DOE/Ocean Energy Program. The Pilot Plant Project is a natural technological progression from OTEC-1, and may culminate in the deployment and operation by industry of a 40 MWe closed-cycle OTEC plant.

The major objectives of the OTEC-1 test facility tests were to assess heat exchanger technology, provide power system performance data, evaluate biofouling countermeasures, assess the environmental effects of OTEC-1 operations and provide the pilot plant program ocean integration data on hulls, mooring and cold water pipes. The United States Naval Ship (USN) CHEPACET, a mothballed WW II tanker, was selected for use as the test bed vehicle. After inspection, repair and reactivation of shipboard systems, and installation of the CWP attachment equipment, a 1 MWe heat exchanger test article and experiment support systems were installed. The CHEPACET (referred to as OTEC-1) was deployed at a site located approximately 12 nautical miles off the west coast of the Island of Hawaii. This activity involved: placement of the deepest moor of this size ever performed; design, fabrication, deployment, operation, release and recovery of the CWP; OTEC operation in a grazing mode; operation in a single point mooring array; and demonstration of the near suction platform design that enabled the test period to last four months and demonstrated the feasibility of deployment and at-sea operations of a large-scale OTEC plant.

The OTEC Pilot Plant Program Opportunity Notice (PON) was issued late in FY 80. Responses to the PON in FY 81 exhibited significant interest in shell-mounted systems. Two proposals were selected for one year conceptual design beginning in mid-FY 82. Both proposals were sited adjacent to the existing Kahe Point power station, owned by the Hawaiian Electric Company (HECO). HECO and the State of Hawaii were members of both consortia and contributed to the cost-sharing.

One contractor proposed to design a 40 MWe net power plant on a fixed tower. The plant would be located one mile offshore from Kahe Point, Oahu, HI in 328 feet of water. The design employed current SOA off-shore oil rig technology for the tower and included condensers located at a depth of 150 feet, evaporators located at a depth of 280 feet and a steel CWP. The CWP was 33 feet in diameter and extended to the bottom (328 feet) running into the deep containment of the total length of the tower. The contractor's proposed design was aluminum finned plate using freon-22 as the working fluid. A single turbine-generator was located atop the tower and was nominally rated at 50 MWe. The net power produced was to be transmitted to a land-based distribution station via trenched and buried submarine cable.

The second contractor proposed a 40 MWe plant constructed on an artificial island. This island would be located 600 feet offshore from Kahe Point, Oahu, HI, in 28 feet of water. The OTEC plant would contain a warm water intake at the HECO's 600 MWe fossil fuel plant, exhaust condenser coolant to enhance the warm water temperature. The system would include: four 10 MWe electrical power modules (each with two condensers and two evaporators and one four-stage axial turbine-generators), and a composite lightweight concrete and fiberglass reinforced plastic CWP, 30 feet in diameter and 13,100 feet in length. The heat exchangers are titanium tube construction employing a horizontal tube and shell design and ammonia as the working fluid. The proposed deployment technique uses a combination of floatation tanks and anchors for installing the CWP on the sloping sea floor.

The conceptual design has been completed and included tradeoff analyses, the preparation of layout drawings, design reports, environmental impact statements, cost estimates, commercialization plans.
and the initiation of environmental data accumulation. The land-based design has been selected to advance to Preliminary Design. This 18-month effort is scheduled for completion during the first quarter of FY 85.

**STATE OF TECHNOLOGY ASSESSMENT AND REMAINING AREAS OF UNCERTAINTY**

A evaluation of the state of development of ocean energy systems has been completed. Each subsystem of the various options such as land-based OTEC-closed cycle, wave, etc. was considered. This evaluation for closed and open cycle land-based OTEC is shown in table I. A part of this evaluation was the determination of areas of uncertainty in the technologies as shown in table II. The subjects in table II are those presently under consideration in the DOE FY 1984 ocean program formulation.

### TABLE I. ASSESSMENT OF STATE OF TECHNOLOGY FOR CLOSED AND OPEN CYCLE OTEC

<table>
<thead>
<tr>
<th>KEY STATE OF TECHNOLOGY</th>
<th>OPEN CYCLE OTEC</th>
<th>CLOSED CYCLE OTEC</th>
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<td>2. ADVANCED CONCEPT</td>
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<td>13. CONCEPTUAL UNDERSTANDING</td>
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<td>18. SITE, DEPTH OR SIZE DEPENDENT</td>
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### TABLE II. AREAS OF UNCERTAINTY

- Cold Water Pipe and Foundation Deployment Techniques
- Geotechnic and Soil Mechanics Factors (including slope stability) for Soil/Platform and Soil CWP Interactions
- Improvement of Heat Exchanger Water Side Heat Transfer to Decrease Size of Heat Exchanger and Analytical Modeling
- Life Expectancy of Low-Cost Heat Exchangers as a Function of Corrosion, Fouling, Structural Integrity, and Materials
- Understanding Coastal Zone Impacts on Recirculation and Discharge Plume
- Statistical Variability of the Ocean Thermal Resource and other Fluctuating Environment Conditions (meteorological, chemical, geological, physical oceanographical)
- Operational Scalable Data From a Fully-Integrated OTEC System in a Seawater Environment
- IM&R and Retrieval of Submerged Components — Up to 5000 foot depth and 70° slopes
- Validated Computer Codes for Predicting CWP (Shelf-Mounted and Suspended) Loads and Responses
- Distribution of Non-Condensible Gases in a Plant and Their Impact on Open Cycle System Performance
- Long-Term Materials Characteristics for CWP
- Electrical Cable Termination Design
- Effect of Redistribution of Oceanic Properties
- Hydrodynamic Loads on CWP (suspended or shelf-mounted) Above Reynolds’ Number of 10^4
- Scalable Open-Cycle OTEC Turbine Performance Data
- Electrolysis Efficiency for Plantships
- CWP Platform Connection Hinge and Seal Validated Design Test
- Direct Contact Heat and Mass Characteristics of Sea Water at OTEC Conditions
- Major Effects of Impingement/Entrainment on Plant Design and the Environment
- Anchor Hardware for Both Steep Slopes and Rock Conditions

### TABLE III. RESEARCH ACTIVITIES

--Thermal Resource ROC
- Physical Oceanography
- Geologic/Geotechnical
- Geologic/Geotechnical
- Biological
- Chemical
- International Law
- Federal Regulations

### TABLE IV. ENVIRONMENTAL REGULATIONS

- ROC
- Comp