DOE/ET/4064 -- 1 (vol. 3)

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NEW YORK, N. Y.

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18351-10 (W-10,020)

OCEAN THERMAL ENERGY CONVERSION
(OTEC) PLATFORM CONFIGURATION AND INTEGRATION**MASTER** FINAL REPORT
VOLUME III

MN ONLY

DEVELOPMENT PLAN
FOR
DEMONSTRATION UNIT**NOTICE**

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Prepared For:
U. S. Department of Energy
Contract Number EG-77-C-01-4064

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1. INTRODUCTION

This report summarizes studies conducted by Gibbs & Cox, Inc. under Department Of Energy Contract No. EG-77-C-01-4064 relating to the OTEC Platform Configuration and Integration study.

1.1 The OTEC Concept

The Offshore Thermal Energy Conversion (OTEC) power system is based on the Rankine thermodynamic cycle, utilizing working fluids such as ammonia capable of boiling and condensing over small temperature ranges in a closed system. Solar energy, stored in warm ocean surface waters, is transferred to the working fluid in a large heat exchanger, thereby causing evaporation of the working fluid. The vapor phase fluid passes through a low pressure turbine and then to a condenser cooled by waters pumped from ocean depths up to 3,000 feet. The condensed working fluid is then returned to the warm water heat exchanger (evaporator), and the cycle is renewed. Energy extracted by the turbine is used to generate electric power either for transmission to shore or for direct usage in an associated, energy-intensive manufacturing, chemical processing use.

1.2 OTEC Program

The OTEC Program schedule calls for the deployment and at-sea test of the OTEC plant facilities. The first test is called OTEC-1, signifying a test of the 1 MWe power cycle module. OTEC-1 is planned for FY 1980-81. OTEC modular experimental plants are planned for FY 1982-83 to test a power module between 10 MWe and 20 MWe in size. There are contracts currently awarded that deal with three major subsystems of the OTEC plant. One set of contracts is involved with the design of various size power cycle modules. Another set of contracts is involved with the configuration of the electric cable subsystem of both the riser/umbilical and bottom transmission cable. A third set of three contracts is involved with the configuration analysis of the OTEC Commercial Plant platforms. This report describes the Gibbs & Cox, Inc. studies conducted under one of these three contracts.

1.2 OTEC Program (Continued):

A comprehensive study of the Cold Water Pipe (CWP) is planned for FY 78 involving preliminary design of the CWP for the OTEC Modular Experiment. Other programs planned for FY 1978 besides the proposed effort of this RFP are an analysis of the stationkeeping subsystems for the modular experiment OTEC plant and an analysis of large system construction techniques.

After the major subsystem configuration studies have been completed, a system integration design contract will be awarded. It will be the responsibility of the systems integration contractor to design all OTEC subsystems (except the Power System and Energy Transmission System) into one integrated Ocean System. A separate contractor will integrate all the OTEC components into the working OTEC plant, and then deploy the plant and operate it at sea.

1.3 Project Overview

The purpose of this project is to evaluate six candidate hullforms as candidates for the OTEC Commercial Plant. The six hullforms will be systematically evaluated to rank them in order of preference considering factors such as cost, schedule and risk. Conceptual designs of two of these plants will then be conducted, and a plan for development of a Demonstration Plant will be prepared.

The project is being conducted under the following nine (9) tasks:

- Task I Data Assembly and Synthesis: Development of a data bank of OTEC-related documentation.
- Task IIA Systems Evaluation and Requirements: Definition of Top Level Requirements and an assessment of factors critical to the selection of hull configuration and size; quantification of payload requirements and characteristics; sensitivity of system characteristics to site selection.
- Task IIB Evaluation Plan: Development of a methodology for systematically evaluating the candidate hullforms, based on interrelationships and priorities developed during Task IIA.

1.3 Project Overview (Continued):

- Task III Technology Review: Assessment of current technology and identification of deficiencies in relation to OTEC requirements; development of plans to correct such deficiencies.
- Task IV Systems Integration Evaluation: Formal evaluation of the six (6) candidate hullforms in relation to site and plant capacity (effective megawatts) to quantify cost/size/capability relationships, leading to selection of an optimum Commercial Plant.
- Task V Conceptual Design: Development of Conceptual Design documentation for two selected Plants to identify plant characteristics to the level of detail required to quantify cost and schedule.
- Task VI Facilities and Equipment: Identification of the facilities and equipment necessary to build and deploy the OTEC Commercial Plant.
- Task VII Development Plan: A plan for the development of an OTEC Demonstration Plant including funding, key milestones, fallbacks, etc.
- Task VIII Cost, Schedules: Detailed assessment of cost and scheduling requirements for the OTEC Commercial Plant.
- Task IX Site Sensitivity: Assessment of the sensitivity of Plant characteristics to the specific environmental characteristics of potential deployment sites.

Gibbs & Cox, Inc. was assisted in this study by four (4) subcontractors:

- Giannotti & Buck Associates, Inc. for evaluation of platform motions, cold water pipe dynamics and environmental analysis.
- Alan C. McClure Associates, Inc. for development of positionkeeping systems and general input related to offshore technology.
- Santa Fe Corporation for systems analysis, cost-benefit analysis, and the Development Plan.
- Worthington Corporation for the design of Seawater Pumps.

1.4 Final Report Organization

This Final Report is divided into three (3) volumes:

- Volume I, Systems Requirements and Evaluation, summarizing Tasks II, III, and IV.
- Volume II, Conceptual Designs, summarizing Tasks V, VI, VIII, and IX.
- Volume III, Development Plan, summarizing Task VII.

This volume, Volume III, is the Development Plan for a Demonstration Unit in which the rationale for deciding on the recommended demonstration unit size is presented and a preliminary development plan is outlined.

1.5 Definitions

Throughout this and the other volumes, reference will be made to the OTEC Ocean System, Power System and Transmission System. For this study, the Ocean System consists of those functional elements necessary to support the payload which generates and transmits electrical power from the platform to shore. These elements are defined on the Work Breakdown Structure shown in Figure 1.3-1 to consist of the Hull, Seawater, Position Control and Support Systems and related engineering sub-elements. The WBS shown in the Figure was modified at the completion of Task IV. However the WBS shown in Figure 1.3-1 was used as a basis for this study and is carried through for consistency.

The Power System consists of those elements necessary to convert the seawater system temperature differentials into electrical power, and consists of the following:

- Evaporator System
- Condenser System
- Turbogenerator System
- Ammonia and Nitrogen Transfer and Storage System

Figure 1.3-2 defines the interfaces between the Power System and the Seawater System as used throughout this study.

FIGURE 1.3-1

PROPOSED THIRD LEVEL OCEAN SYSTEM WORK BREAKDOWN STRUCTURE

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FIGURE 1.3-2
POWER SYSTEM/SEAWATER SYSTEM DEFINITION

1.5 Definitions (Continued):

The Transmission System consists of the power conditioning equipment and cable necessary to transmit the generated power ashore. Both the Power and Transmission System characteristics reflected in this study reflect DOE input. The Gibbs & Cox, Inc. scope of work did not involve any design effort relative to these systems.

2. REQUIREMENTS

2.1 Requirements

The purpose of Task VII is to recommend a Demonstration Unit size based on demonstrating economic viability to utility users of a commercial OTEC system but recognizing facility constraints and costs. A preliminary development plan for the recommended demonstration system is also required.

In the analysis, heavy emphasis is put on resolving risk from an engineering point of view, and proving economic viability from a utility point of view. The recognition of facility constraints and costs is interpreted to mean the Demonstration Unit should be built using current or existing facilities or barges if possible; and also implies keeping the investment and operating costs as low as possible.

2.2 Limitations

A considerable amount of data was provided and/or generated in Task IV, particularly as it pertained to the hull form, component sizes and materials. The Task V efforts included the design of a new hull form with externally mounted heat exchangers. This was different from those detailed in Task IV. The Task V effort also fixed on a 400 MW size as a commercial unit; also different than those considered in Task IV. The Task V and Task VI efforts ran at least concurrently with or behind the Task VII effort due to schedule changes and compression. Therefore, the benefit of having a completed Task V and Task VI design, complete with cost schedule, construction, deployment, operating and test plan in hand could not be fully used before deriving a Demonstration Unit size. These facts limited the analysis somewhat and dictated the methodology, as will be explained in subsequent sections.

3. RISK ASSESSMENT SURVEY

3.1 Procedures

A risk assessment survey was sent to key personnel on the Gibbs & Cox, Inc. OTEC team. The survey was designed to elicit comments and recommendations as to what would be required before; (1) a commitment could be made toward construction of an OTEC Demonstration Unit, and (2) what would be required on an OTEC Demonstration Unit in order to convince utility users of the economic viability of a commercial system. The survey was designed to lead to individual subsystem programs and plans to further reduce risk before the Demonstration Unit should be started, and to sizing a Demonstration Unit and developing a plan to demonstrate the chosen unit. The survey used a matrix array checklist approach for each of the Work Breakdown Structure (WBS) elements and asked for judgments and comments on:

- Updating prior risk assessments to today's knowledge and applied to the 400 MW commercial units under consideration.
- Indicating current technical difficulties and commenting on requirements prior to commitment to build a Demonstration Unit.
- Specifying the components or functions comprising the WBS element which need to be demonstrated in order to satisfy utility users of the economic viability of a commercial system.
- Indicating facility constraints at existing shipyards and fallbacks based on accomplishing a lesser effort than recommended using existing facilities and limiting costs.
- Indicating remaining cost, schedule, and technical risk in going from an assumed successful Demonstration Unit to a full scale commercial OTEC plant.

3.2 Typical Example

A sample page from the risk assessment survey is included as Figure 3.2.1 This page is for Hull Systems Arrangements (WBS A.3). The line for Mission Support (WBS A.3.1) shows, for example, an increased risk associated with the change to

FIGURE 3.2-1

DEMONSTRATION UNIT SIZE ANALYSIS

	CURRENT RISK ASSESSMENT		BEFORE COMMITMENT TO DEMONSTRATION UNIT				REQUIREMENT FOR DEMONSTRATION UNIT TO VERIFY ECONOMIC SYSTEM VIABILITY				
	PREVIOUS RISK ASSESSMENT - TASK III	MODIFIED RISK ASSESSMENT DUE TO REFERENCE TO DATE	NO FURTHER REQUIREMENTS - ITEMS ARE OFF-SHELF	PAPEP STUDIES - ANALYTICAL, FEASIBILITY, DESIGN, ETC	MODEL TESTING REQUIRED	INDIVIDUAL COMPONENT DEVELOPMENT & TEST	NOT REQUIRED TO BE DEMONSTRATED	TEMPORARY FACILITIES ACCEPTABLE	PARTIAL SCALE COMPONENTS	FULL SCALE COMPONENTS BUT LIMITED RUNS	FULL SCALE ALL COMPONENTS
A. HULL SYSTEMS (Cont)											
3. ARRANGEMENTS		(1)		(2)							
1. MISSION SUPPORT	8/4	4/4		8/8							
1. Power System											
2. Trans. Sys.											
3. Fluids & Star.											
2. PERSONNEL SUPPORT	9/9	9/9		10/10			10/10				
1. Living, Recr., Sanitary											
2. Commissary, Laundry											
3. Medical											
4. Admin.											
5. Storage											
3. PLATFORM SUPPORT	9/9	9/8		9/9			9/9				
1. Mach. Spaces											
2. Pos., Contr., Spaces											
3. Command, Contr., Communication											
4. Tankage, Storage											

(1) Increased risk resulting from switch to external H/X's.

(2) Analytical studies would reduce risk to acceptable testing, etc-N/A.

(3) This will fall out of full scale power system demos.

- CURRENT TECHNICAL DEFICIENCIES: Interface between payload components and hull system not now due to lack of equipment parameters.
- REQUIREMENTS FOR DEMONSTRATION UNIT: Demonstrate payload/hull interfaces.
- FACILITIES CONSTRAINTS/FALLBACKS: None
- REMAINING RISK: Risk should be reduced as a fallout of Pilot Plant equipment demonstration.

Note: The first of each of the two risk factors represents an assessment based on a 100 MW Demonstration Plant while the second risk factor applies to a 500 MW Demonstration Plant.

3.2 Typical Example (Continued):

external heat exchangers from a numerical value of 4 vice the Task IV value of 5 for the 100 MW size plant. Note that the risk ratings are based on a 1 to 10 scale where the low numbers imply high risk. The survey sample shows that analytical and engineering studies of external heat exchangers should reduce the risk assessment to a level of 8 in this WBS area.

3.3 Summary or Risk Assessment Survey

The survey was completed based on the WBS in effect at the time and not on the revised one provided by DOE in March. Therefore, rather than present the total survey results per se, an abbreviated table representing a summation of risk assessment as it relates to the revised WBS elements is shown in Figure 3.3.1. Essentially, this table shows that the economic and technical risk remaining is low assuming the developmental actions anticipated are completed. These assessments and developmental actions are reviewed in a non-quantitative manner in Section 4.

	HULL STRUCTURE	POSITION CONTROL SYSTEM	PLATFORM SERVICE SYSTEM	OUTLET AND FURNISHINGS	SEAWATER SYSTEM	COLD WATER PIPE SYSTEM
PREVIOUS ASSESSMENT OF RISKS	6	9	8	9	5	5
DEMONSTRATION PLANT RISK	3	9	9	10	8	7
FORECAST OF RISKS FOR A COMMERCIAL PLANT AFTER SUCCESSFUL DEMONSTRATION	9	10	10	10	9	9

Note: Risk factors used above and in Figure 3.2-1 correspond to Volume II Technical Risk criteria as follows:

High Risk	1.	Technology is non-existent and cannot be satisfactorily developed within the time frame of the OTEC program.
	2.	Technology is very limited, and massive R&D efforts would be required, with high risk.
	3.	Technology is limited, and extensive R&D programs required to solve the problem represent a relatively high risk.
Moderate Risk	4.	Technology is marginally well developed but cannot be applied to offshore environment or to large OTEC platforms without extensive R&D, with moderate risk.
	5.	Technology is well developed and verified, but cannot be applied to offshore environment or to large OTEC platforms without nominal R&D programs of moderate risk.
	6.	Technology is well developed and verified by limited offshore experience, but not to large floating platforms.
	7.	Existing technology can be extended to OTEC platforms by application of nominal low-risk R&D.
Low Risk	8.	Existing technology can be extended to OTEC platforms with relatively little R&D, requiring no testing.
	9.	Existing technology requires little R&D and no testing to be extended to OTEC platforms.
	10.	Existing technology is fully adequate for use in OTEC platforms with no additional development.

4. OTEC DEMONSTRATION PLANT OCEAN SYSTEMS REQUIREMENTS

4.1 Introduction

This section discusses, in a general or non-quantitative manner, and from the Ocean Engineer's point of view, the capabilities required for the OTEC Demonstration Plant in light of current platform concepts and related risk. All elements of the Work Breakdown Structure are addressed.

There are several issues which should be addressed prior to discussing the WBS elements. First, it is expected that the OTEC-1 test will serve to demonstrate many aspects of OTEC technology, and additional benefits could be gained from this program at nominal cost. It is suggested that the OTEC-1 operational scenario and test plan be reviewed in light of this discussion to determine potential risk reduction.

The second issue relates to Power System demonstration. This phase of the OTEC program is beyond the scope of this effort, yet is integrally tied to the Ocean System test and demonstration program, particularly the Seawater System. The size and operating dynamics of the Power System selected for demonstration will have a major impact on the size and operating dynamics of related Ocean System components. At this time, DOE plans tentatively call for a 10 to 20 MW Pilot Plant known as the Modular Experiment (basically a Demonstration Plant), though the number and size of heat exchangers, etc. are not defined. If DOE pursues this course, it will become necessary to trade off the additional cost of demonstrating Ocean System elements for a 50 MW Commercial module or the 400 MW Commercial Plant against the potential reduction in risk.

4.2 Hull Structure

4.2.1 Configuration

The selection of the ship and semi-submersible located at Hawaii for the baseline Gibbs & Cox, Inc. 400 MW designs significantly reduces risk relative to, for example, the spar or submarine since both approximate state-of-the-art concepts. Likewise, the reduction in platform size afforded by smaller,

4.2.1 Configuration (Continued):

externally mounted heat exchangers reduces platform risk though increasing that of the heat exchangers. The ship platform is currently within the SOA, though its proportions vary from normal standards. Therefore, the ship is considered to be a fairly straightforward extension of existing technology, with no demonstration required beyond SOA analytical studies and model tests.

The semi-submersible is significantly larger than the current SOA, which will necessitate a far more extensive program of analytical studies and model tests than would normally be accomplished. However, it is considered feasible to carry out such a program leading to a Commercial Plant hull design without the expense of demonstration, unless this capability is a fallout to other program demonstration requirements. For example, if a new hull is required for the 10-20 MW Pilot Plant, and the semi-sub is selected for the Commercial Plant, it makes sense to utilize the semi-sub configuration for the Pilot Plant. This would involve little additional cost, and would provide reduced scale results on motions, loads, stresses, drag and other factors which could be extrapolated to the larger Commercial Plant. A particular advantage would be in testing the hull/CWP connection. However, if using the semi-sub configuration for the Pilot Plant results in a significant increase in cost or schedule, the concept should be dropped in favor of a more conventional, lower cost approach.

4.2.2 Physical Structure

Reconsideration of cost and fabricability of the current 400 MW ship and semi-sub designs has led to selection of steel for hull structure vice reinforced concrete. This has significantly reduced the overall risk associated with structure, in conjunction with the more SOA size of the platforms. Based on this, the risk in structural design can be reduced to acceptable levels by a combination of analytical studies and model tests. The depth of these efforts would be far greater for the semi-sub, and the confidence in the Commercial Plant design would be enhanced by a semi-sub Pilot Plant. However, as noted in Section 4.2.1, this should not be considered as a driving requirement.

4.2.3 Arrangements

The switch to external heat exchangers (H/X) has increased the risk associated with the H/X hull interface and related arrangements. The major risk is in the H/X, which is therefore beyond the scope of this study. From the stand-point of overall platform integration, the attachment of external heat exchangers is considered an area of risk. The ability to properly integrate the mission support equipment, personnel support and platform support is primarily dependent on proper analysis, and in some cases the use of mock-ups, such as the Central Control Station. Both of these approaches are conventional and do not require "demonstration" within the context intended here. Both the OTEC-1 and Pilot Plant efforts should satisfactorily reduce risk associated with arrangements as part of normal program development.

4.2.4 Motions

Platform motions per se are not considered to be a major risk area, since current analytical tools and model tests are sufficiently accurate to predict platform response to the specified environment. As noted previously, the use of a semi-sub Pilot Plant hull would provide added confidence in motion predictions for the Commercial Plant. However, this should not be the driving consideration. It is noted that the use of external heat exchangers significantly complicates the use of current analytical tools due to the unusual and irregular below-water hull shape. However, this effect can be mitigated by the use of non-tight fairings, and model tests using larger models to reduce scale effects.

The effect of platform motions on the CWP and hull/CWP connection remains a very high-risk area which requires demonstration. This is discussed in Section 4.6.1.

4.2.5 Interface Areas

Interface areas in which high risk exists include the hull/CWP connection as discussed in Section 4.6.1 and transmission cable connection to the hull. Both of these areas must be demonstrated, though at a reduced scale, and as part of currently planned test efforts.

4.2.5 Interface Areas (Continued):

The interface between Power System components and the hull remains an area of nominal risk, particularly the external H/X hull interface. This is discussed in Section 4.2.3.

4.3 Position Control System

4.3.1 Static Position Control Sub-System

The relatively benign environment of Hawaii, as well as the smaller size of the current 400 MW platforms, reduce the risk of the Position Control System from earlier levels while the inclusion of external heat exchangers and seawater discharge pipes tend to increase it somewhat. It is anticipated that analyses and model tests will lead to estimates of platform motions and drag forces, and that other DOE/NOAA programs will fully define the environment in so far as position keeping is concerned. With these baseline assumptions, the only remaining elements to consider are the anchors, lines and controls, including winches. If it is possible to simply use multiples of SOA equipment, there will be no need for demonstration. However, if new concepts are considered for the Commercial Plant, they should be demonstrated at partial scale on the Pilot Plant, since such demonstration can be accomplished for little additional cost. If the bottom characteristics at the Commercial Plant site are radically different from those at the Pilot Plant site, such demonstration may not be meaningful, and partial scale demonstration at a more representative site may be necessary.

4.3.2 Dynamic Position Control Sub-System

Comments similar to Section 4.3.1 apply to the dynamic positioning option except that there is significant risk in scaling up results of reduced-size positionkeeping thrusters and other mechanical components. Therefore, a full scale prototyping and testing program for the Commercial Plant thrusters (if used) is recommended, similar to that for the pumps as described in Section 4.6.1.3. In this case, the Pilot Plant could probably be used as a test bed

4.3.2 Dynamic Position Control Sub-System (Continued):

for the full size Commercial Plant thruster, since thruster size is unrelated to Power Plant size as in the case of the pumps.

4.3.3 Interface Areas

The area of primary concern relative to Position Control interfaces is the possible interference of the riser cable and mooring lines, as well as the influence of thrusters on reingestion. In general, these problems can be analyzed with sufficient accuracy to permit program development without the need for special demonstration. However, full scale verification is considered essential.

4.4 Platform Service System

All subsystems of the Platform Service System are comprised of off-the-shelf components, so that such systems can be designed using conventional analytical techniques and installed without special demonstration. The only aspects of the OTEC Ocean System support requirements which present unusual challenges include:

- Conditioning Power System electrical power in such a manner that it can be used for platform electrical power
- Chlorination System distribution and control
- Ammonia leakage detection and correction

Even in these areas, the technology exists to develop the necessary hardware for each successive OTEC platform without prior demonstration.

4.5 Outfit and Furnishings

All elements covered under Outfit and Furnishings for habitability, maintainability, and operability, are well known in the engineering and logistics support community and present no problems peculiar to OTEC.

4.6 Seawater and Cold Water Pipe System

4.6.1 Cold Water Sub-System

4.6.1.1 Cold Water Inlet Pipe (CWP)

The CWP remains the most critical technical issue associated with the OTEC Ocean System, and demonstration is considered essential in predicting loads, stresses, motions and hydraulics. OTEC-1 will provide a great deal of data, though the OTEC-1 CWP is so much smaller than that for the Commercial Plant that a great deal of risk will remain even after OTEC-1. The level of risk will be related to the agreement, or lack of agreement, between measured and predicted response. Hopefully the OTEC-1 program includes such validation. It is also understood that DOE intends to test a 5 foot diameter, 1000 foot CWP using a drilling rig, which should provide additional verification.

Assuming that OTEC-1 and the 5 x 1000 foot CWP tests verify analytical techniques, there should be sufficient confidence in such techniques to proceed to the Pilot Plant without further component testing. If such validation is not achieved and a high level of risk remains, it would be prudent to backfit the OTEC-1 platform with the largest CWP which it can support, at least equivalent to that required for the Pilot Plant, to refine analytical techniques and develop a data base for response analysis. After testing, this CWP can be transferred from the OTEC-1 to the Pilot Plant, which will also serve to demonstrate deployment concepts.

The refinement of analytical techniques resulting from the Pilot Plant tests should result in sufficient confidence to proceed to the Commercial Plant CWP without further demonstration unless there is a change in configuration, materials or flexibility which invalidates the Pilot Plant tests. Likewise, lack of agreement between observed and predicted data may result in unacceptable risk. In this case, it would be necessary to develop an interim demonstration CWP either at full scale or reduced scale somewhere between the 20 and 400 MW size. Contingency planning to suit this option should be considered.

4.6.1.1 Cold Water Inlet Pipe (CWP) (Continued):

Another area requiring demonstration relative to the cold water inlet is the method of filtration (filters, screens, etc.) and combating biofouling. These areas can be demonstrated with a reduced scale CWP. Long term CWP operability and maintainability must also be demonstrated.

4.6.1.2 Cold Water Pipe (Discharge)

The smaller size and reduced loading on the discharge pipe results in reduced risk such that model tests and analysis in conjunction with the parallel CWP demonstration efforts should be adequate without special demonstration. It would be desirable to configure the Pilot Plant discharge to simulate that intended for the Commercial Plant. This would permit validation of both structural and hydraulic calculations as well as thermal mixing and interference effects.

4.6.1.3 Pumps

The cold water pumps are considered to be an item of reasonably low risk up to about 25 MW capacity. Beyond this, there is a very limited SOA, with proportionally higher risk. If cost/benefit/risk studies lead to selection of multiple 25 MW capacity pumps for the Commercial Plant, a prototype full scale 25 MW unit could be demonstrated on a 20 MW Pilot Plant.

If the Pilot Plant is less than 20 MW, its pumps should be sized to suit the Plant capacity rather than being deliberately oversized simply for demonstration. In this case, the prototype 25 MW pump should be built and tested early in the Commercial Plant program and, after debugging, be fitted into that Plant.

Finally, if a 50 MW pump is selected, the potential risks would appear to be low enough that the prototype could be built and tested early in the Commercial Plant program, and installed after the test program was complete. The option of falling back to multiple 25 MW pumps should be considered in the platform design, and incorporated if no major volume or weight penalties accrue.

4.6.1.4 CWP/Hull Connection

Considerations relative to this critical connection essentially parallel those of the CWP itself, Section 4.6.1.1, and a similar demonstration/validation program is proposed. The only additional consideration is the possibility that the OTEC-1 connection will be rigid while that of later plants will be flexible. In this case, it is recommended that the OTEC-1 be backfitted with a reduced-scale flexible connection similar in configuration and materials to that proposed for the Commercial Plant. Demonstration of a flexible connection on OTEC-1 is considered essential if such a connection is proposed for the Commercial Plant.

4.6.2 Warm Water Sub-System

In general, considerations relative to this subsystem parallel those for the cold water system, particularly regarding the pumps and discharges, which are nearly identical. The remaining area, namely the warm water inlet, requires demonstration in one critical area - filtration. It is proposed that various types of filtration systems, including fixed and traveling screens, back flushing etc, be demonstrated at partial scale as part of the OTEC-1 and Pilot Plant programs, such that an optimum filtration concept can be selected for the Commercial Plant. Long-term testing for operability and maintainability is required.

4.6.3 Interference Effects

These effects can be predicted on the basis of analysis and/or model tests with sufficient accuracy to justify proceeding with Pilot Plant and Commercial Plant development. However, due to the criticality of maximizing the warm water resource, validation of these predictions is strongly recommended, both on OTEC-1 and later platforms.

4.7 Systems Engineering

4.7.1 Mission Analysis

Based upon discussions of the Ocean System demonstration requirements in preceding sections, it is apparent that the size and characteristics of the Demonstration or Pilot Plant will be driven by requirements for Power and Transmission System demonstration. Some Ocean System demonstration will naturally fall out of these efforts but will not drive them.

4.7.2 Cost Analysis

A great deal will be learned during both OTEC-1 and the Pilot Plant to enhance the cost estimates of the Commercial Plant. However, no demonstration effort is required.

4.7.3 System Requirements

4.7.3.1 Construction

With the use of steel structures, modular techniques are available which can be accomplished within currently available facilities; therefore, analytical studies are considered adequate for demonstrating the ability to construct OTEC platforms. The joining of major modules afloat has also been accomplished, though primarily abroad, so that the expertise exists to accomplish this critical step on the prototype platform without demonstration. In a sense, OTEC-1 is a partial scale demonstration for the Pilot Plant which in turn is a demonstration for the Commercial Plant.

4.7.3.2 Deployment

Deployment of the OTEC hulls is not considered to be a problem. However, the deployment of the CWP and the installation of external heat exchangers after launching of the hull pose unique problems. However, they are considered solvable, though requiring extensive analytical studies and consultation from experts in the field of offshore materials handling. If these studies do not

4.7.3.2 Deployment (Continued):

reduce risk to an acceptable level, the fallback exists of backfitting a reduced scale CWP to the OTEC-1 platform (not necessarily a functional CWP) to check out procedures and transitional stresses. It is recommended that the Pilot Plant CWP be deployed in the same manner as intended for the Commercial Plant CWP as a form of demonstration.

4.7.3.3 Maintenance

Maintenance and manning concepts can be analytically developed and demonstrated as part of each platform's operational profile, thus forming a valid basis for those of succeeding platforms without supplemental demonstration.

4.7.3.4 Other System Requirements

Comments similar to Section 4.7.3.4 apply to other system requirements.

4.7.3.5 Administrative Requirements

The only potential administrative requirements which might require some form of demonstration would relate to obtaining regulatory agency approvals. However, no such requirements beyond those already discussed have been identified.

4.8 Summary

The following are areas in which demonstration is considered essential before proceeding with the Pilot Plant or Commercial Plant.

4.8.1 Pilot Plant

The following should be demonstrated on OTEC-1 and/or the Pilot Plant as a baseline for developing the Commercial Plant:

4.8.1 Pilot Plant (Continued):

- CWP design, construction and deployment at reduced scale.
- Seawater pumps, up to the capacity of the Pilot Plant (i.e. reduced scale)
- Non-SOA Position Control System components, at full scale if possible.
- Filtration Concepts
- Hull configurations, if additional cost is not prohibitive, at reduced (Pilot Plant) size.
- Power system and Transmission System interfaces.

Each of the above programs is also expected to provide data in the following areas, applicable to follow-on programs:

- Platform loads and motions and related stresses
- Interference and discharge mixing effects
- Maintenance and operation
- Regulatory requirements

5. OTEC DEMONSTRATION PLANT POWER AND TRANSMISSION SYSTEM REQUIREMENTS

5.1 Introduction

The overall OTEC systems requirements analysis would be incomplete without addressing the Power System and Transmission Systems requirements. Throughout the study, Gibbs & Cox, Inc. has been provided planning data on cost, size, weight and shape of the Power Systems. The data have been adequate for the preliminary design phase of the Ocean Systems but have not been adequate to assess OTEC on a complete system basis (e.g. little data for the Transmission System). The impact of these systems from a demonstration viewpoint however, is addressed in subsequent paragraphs. The approach is to discuss the potential impact of choosing various combinations of demonstration hulls and incorporating alternatively sized components of sub-systems. The discussion simply asks what is demonstrated and tends to conclude that risks are not necessarily closed out by demonstrating at less than full scale.

5.2 Power System

5.2.1 Turbines

Although there are no ammonia driven turbines producing electricity today, there is agreement within the OTEC turbine community that turbines for OTEC can be developed. It is understood that the first one would be for about 10 MW net. and that two could be mounted on the same shaft to provide a nominal 20 MW net capability. Further it is understood that the 10 MW net turbine could be scaled up as a subsequent development to a 25 MW net turbine and that two of these ammonia driven turbines could also be used on one shaft to provide 50 MW net power.

Figure 5.2.1 is a matrix array of the possible combinations which were assumed for demonstration. If the 10 MW turbine were to be used on any of the hull alternatives indicated and if the "demonstration" were successful, a subsequent "demonstration" would be required to prove the new 25/50 MW turbine combination to utility users. From the deficiencies noted in the array, it is obvious that, if the Commercial Plant is sized at 400 MW, or if anticipated OTEC plants are envisioned at 100 MW and higher, the demonstration should be designed to test the full scale turbine in the anticipated operating environment. Therefore, the turbine intended for the 50 MW module is recommended as the turbine to be demonstrated.

HULL ALTERNATIVE	TURBINE ALTERNATIVE			
	10 MW	20 MW (2 x 10)	25 MW	50 MW (2 x 25)
EXISTING HULL	<ul style="list-style-type: none"> • Must develop 25 MW turbines later • Must prove full scale later. • Different "G" loads than for Comm'l. Plant 	<ul style="list-style-type: none"> • Same as left • Same as left 	<ul style="list-style-type: none"> • Will prove turbine itself, but not full scale turbine/generator combination • Same as left • Same as left 	<ul style="list-style-type: none"> • Will prove full scale turbine/generator combination • Same as left
SCALE OF A COMMERCIAL 400 MW SYSTEM	<ul style="list-style-type: none"> • Same as above 	<ul style="list-style-type: none"> • Same as above 	<ul style="list-style-type: none"> • Same as above 	<ul style="list-style-type: none"> • Same as above
SELECTED PORTIONS OF A FULL SCALE 400 MW PLANT	<ul style="list-style-type: none"> • Does not apply 	<ul style="list-style-type: none"> • Does not apply 	<ul style="list-style-type: none"> • Same as above 	<ul style="list-style-type: none"> • Same as above
FULL SCALE COMPLETE 400 MW PLANT	<ul style="list-style-type: none"> • Does not apply 	<ul style="list-style-type: none"> • Does not apply 	<ul style="list-style-type: none"> • Does not apply 	<ul style="list-style-type: none"> • Best combination • Successful demo proves Commercial Plant

FIGURE 5.2-1

RISK ASSESSMENT MATRIX: AMMONIA DRIVEN TURBINES

5.2.2 Heat Exchangers

Heat exchanger efficiency is probably the most critical factor involved with the success of the OTEC concept. The limited difference in temperature between the heat addition cycle and the heat rejection cycle leads to a constrained energy transfer per unit mass to and from each temperature reservoir. This fact results in a requirement for a very large mass flow to accommodate the energy transfer, and a very efficient means of transferring energy.

In any heat exchanger, the energy transfer capability is a function of the temperature difference across the boundaries and the physical parameters existing at the boundaries, such as fluid turbulence and surface scale build-up. In the OTEC application the temperature differences in both the evaporator and condenser are on the order of 6-8 degrees Fahrenheit. Due to this small temperature difference, turbulence, scaling and bio-fouling play critical roles in heat exchanger performance. Turbulence enhances heat transfer by mixing while scaling and bio-fouling inhibit heat transfer by insulating and restricting flow. Turbulence is a function of system geometry and fluid velocity. Velocity, therefore, has a two-fold effect: It determines the turbulence levels which affect the heat transfer rates for a given temperature difference, and it determines the mass flow and the total energy transfer capability. For these reasons, given a heat exchanger system, the scaling and bio-fouling and turbulence effect will determine the efficient range of power plant operations. Therefore, the overall heat exchanger performance will have to be determined in a full scale application.

Figure 5.2.2 represents alternatives in heat exchanger operational designs which can be used in the Demonstration Plant. Risk for different sized heat exchangers assumes a successful demonstration at the corresponding level shown. The assumed alternative designs should be sized to be consistent with arrangements and other Power System components for each of the platforms considered. For example, a partial scale, partial flow heat exchanger could be sized for a 25 MW transfer rate, but used with a 10 MW turbine on the demonstration unit. This would result in a partial scale, partial flow heat exchanger alternative.

In considering the applicability of each alternative, it is obvious that all partial flow alternatives leave risk in scale up due to the critical nature of the fluid velocity function. If turbulence is not accurately represented, the commercial plant heat transfer rates cannot be verified.

HULL ALTERNATIVE	HEAT EXCHANGER ALTERNATIVES			
	PARTIAL SCALE PARTIAL FLOW	PARTIAL SCALE FULL FLOW	FULL SCALE PARTIAL FLOW	FULL SCALE FULL FLOW
EXISTING HULL	<ul style="list-style-type: none"> Fluid turbulence and head losses are not validated. 	<ul style="list-style-type: none"> Full scale deployment practices not verified Heat transfer rates are not representative. 	<ul style="list-style-type: none"> Fluid turbulence and head losses are not validated Same as left 	<ul style="list-style-type: none"> Risk minimized
SCALE OF A COMMERCIAL 400 MW SYSTEM	<ul style="list-style-type: none"> Same as above 	<ul style="list-style-type: none"> Same as above Same as above 	<ul style="list-style-type: none"> Same as above 	<ul style="list-style-type: none"> Same as above
SELECTED PORTIONS OF A FULL SCALE 400 MW PLANT	<ul style="list-style-type: none"> Same as above 	<ul style="list-style-type: none"> Same as above Same as above 	<ul style="list-style-type: none"> Same as above 	<ul style="list-style-type: none"> Same as above
FULL SCALE COMPLETE 400 MW PLANT	<ul style="list-style-type: none"> Does not apply 	<ul style="list-style-type: none"> Does not apply 	<ul style="list-style-type: none"> Does not apply 	<ul style="list-style-type: none"> Same as above Best combination Successful demo proves Commercial Plant

FIGURE 5.2-2

RISK ASSESSMENT MATRIX: HEAT EXCHANGERS

5.2.1 Heat Exchangers (Continued):

When comparing the partial size and full size, full-flow alternatives, the selection process becomes one of economic trade-off. All risk areas, including transfer rates, scaling predictions, and construction difficulties (depending on the size of the partial scale heat exchanger), with the exception of full scale deployment practices, could be adequately modeled at either full scale or partial scale. The question becomes one of utility acceptability of the scale up assuming the demonstration is successful. Also, as with all system components, smaller scale effort may result in a slight loss in efficiency, making the scaled down plant less economical to operate.

It is concluded that the Demonstration Plant should incorporate full scale, full velocity heat exchangers, in order to verify heat exchanger performance under conditions of intended use.

5.3 Energy Transmission System

It is understood that the underwater transmission line capable of carrying 400 MW of electric power is not yet developed or tested. Also to be developed and tested is a scheme of attachment to the platform, a method of transporting and laying the cable, and a process for inspection, repair and replacement.

The Transmission System is risky to the utilities because of the above elements. Furthermore, in a demonstration, one would want to prove that the line could carry the full electrical load, that the connecting scheme is reliable, and that the physical loads in the system were well known and within design criteria. The matrix in Figure 5.3.1 shows the drawbacks of demonstrating less than 400 MW. Presuming that the transmission line is designed for demonstration for less than 400 MW, all the physical parameters for a 400 MW line must be demonstrated again and therefore, a risk remains. If a 400 MW transmission line is used on a demonstration at less than a full scale physical plant, the link up and motion effects cannot be fully proved. And, if a demonstration plant with anything less than a 400 MW output is demonstrated, the transmission line cannot be tested to full load.

Given a 400 MW commercial unit, the conclusion is that a 400 MW transmission line should be tested with a 400 MW plant at 400 MW electrical output. This omits from consideration the eventual 3200 MW energy park concept which may or may not use a single 3200 MW transmission line.

HULL ALTERNATIVE	TRANSMISSION LINE ALTERNATIVES		
	LESS THAN 400 MW	GREATER THAN 400 MW	3,200 MW ENERGY PARK
EXISTING HULL	<ul style="list-style-type: none"> • Must develop for full scale 400 MW and demo again. • 400 MW line characteristics not proved. 	<ul style="list-style-type: none"> • Line not fully loaded in this test. • Inadequate proofing 	<ul style="list-style-type: none"> • Same as left
SCALE OF A COMMERCIAL 400 MW SYSTEM	<ul style="list-style-type: none"> • Link up might be different then for full scale. • Motions affects on link up and spatial relationships not proved. 	<ul style="list-style-type: none"> • Same as above • Same as left 	<ul style="list-style-type: none"> • Same as above • Same as left
SECECTED PORTIONS OF A FULL SCALE 400 MW PLANT	<ul style="list-style-type: none"> • Same as above 	<ul style="list-style-type: none"> • Same as above • Same as left 	<ul style="list-style-type: none"> • Same as above • Same as left
FULL SCALE COMPLETE 400 MW PLANT	<ul style="list-style-type: none"> • Same as above • Cannot demonstrate total plant output. 	<ul style="list-style-type: none"> • Same as above • Can conduct tests and verify performance for one plant. 	<ul style="list-style-type: none"> • Should explore multiple path link to shore. • 400 MW demo will leave 3,200 MW uncertainty.

FIGURE 5.3-1

RISK ASSESSMENT MATRIX: ENERGY TRANSMISSION

5.4 Demonstration System Risk Summary

The preceeding arguments which relate individual risk elements to alternative demonstration concepts, point strongly toward full scale commercial components in a Demonstration Plant. This indication is present when the individual risk elements of ocean engineering and the power and transmission elements are taken as a group, and when the impact of small variances can lead to a less than adequate product.

6. ELECTRIC UTILITY SURVEY

6.1 Purpose

The elements of this survey might very well have been included in the cost section of the risk assessment survey. However, the utility survey and the engineering survey are taken from two different perspectives. The engineers are sellers and the utility managers are buyers. So the capabilities assessment was from an engineer's and builder's point of view, the Power System and Transmission System were discussed from a system manager's point of view, while this section looks at the OTEC plant from a utility executive's point of view. Three utilities were contacted. Discussions developed institutional factors which might impact the utility decision-making process vis-a-vis an OTEC commercial plant. Other telephone discussions were conducted with knowledgeable personnel at the Energy Regulatory Administration/DOE. The consensus of these discussions will be described in the following paragraphs.

6.2 Industry Overview

The utility industry is very conservative in its investments attitudes. The industry is mature, is comfortable in dealing with knowns and is uncomfortable in dealing with unknowns. It is slow to change, stable, and is accustomed to dealing with a technology that has matured over decades with an unparalleled reliability, and is constrained by a variety of regulations regarding safety, environment and profitability. Utilities do not, in general, either themselves or through their technology organization, have significant funds available for extensive research, development and demonstration (RD&D) programs, but they have in the past supported new programs when economic or technological benefits have been overwhelming - such as in the case of nuclear power plants developed and funded by the federal government. Yet in the case of the floating nuclear plant, which is a potentially innovative concept to reduce capital investment requirements through mass production of power plants, there is only one utility willing to take the risk; and they are encountering significant environmental, social and legal obstacles.

On the other hand, there are the recent trends in consumer advocacy, public utility commission pressure, and constrained capital markets which tend to

6.2 Industry Overview (Continued):

force the utilities to invest and experiment in reducing the cost of retail electricity. These forced investments may not be capital in nature, and are most probably the low dollar items which reduce current operating costs.

6.3 Investment Criteria

A common topic in the discussion with utilities was a confirmation of the benefit-cost methodology used in Task IV for evaluation of alternative hulls. The utilities seek alternate ways to provide electric power, constantly comparing existing plant and equipment to new possibilities and expansion plans. Inherent in their analysis is a recommendation from the utility engineer that the proposed new item is technically sound and the engineering performance is known to a high degree of accuracy. Next, a 30 to 40 year discounted cash flow analysis is done using the utility cost of capital. One company indicated 10 percent was acceptable in the analysis; the other company gave as their current cost of capital 14.9 percent. The utility staff personnel then do risk assessments, and a sensitivity analysis for each risk parameter is conducted. When all quantifiable elements have been analyzed, the unquantifiable factors are subjectively rated on a 1-10 scale with reasons for the assessment documented. The results of both analyses are then presented to the corporate officers for decision. The thrust here is that this type of analytical effort is done carefully and as accurately as possible. In an environment of scarce capital, there is little likelihood that a utility will make a commitment on OTEC without similar analyses which support an investment decision based on return on investment criteria.

6.4 Business Risks

Further areas of business risk not discussed under Task IV report pertain to the interplay among the OTEC commercial platform, the utility facilities and capital plant. Several areas discussed below warrant noting in order to emphasize risk elements of OTEC commercial plants.

6.4.1 Load Matching

Since the OTEC plant is a baseload plant, the question of reserve requirements in case of OTEC plant failure, or higher than expected outages, may deter a utility from choosing OTEC over known expansion alternatives. The seasonal and diurnal variations in output from an OTEC plant play a more significant role than previously anticipated. Yearly and daily load curves must be compatible with a utility's reserve capacity requirements. This compatibility must be rigorously analyzed.

6.4.2 Transmission System Redundancy

Since utilities usually have multiple entries to their power grids, why have only one transmission line/route to shore from the OTEC plant? A redundant capability is desirable and could be necessary to reduce the risk to acceptable levels. It is noted that discussions with transmission line development personnel have indicated the need for spare transmission lines, but this has been in the context of a single line/route to the power grid rather than multiple routes. Transmission System redundancy should be addressed in subsequent OTEC planning.

6.4.3 Forced Outage Rate

The utility will want to see actual forced outage data from the demonstration unit. There is a feeling that scale models could not fully reveal all of the problems and permit the full investigation of the realities of owning and operating the plant. The term "capital-cost ratio" i.e., annual production/operating costs divided by the investment cost, must be accurately known in order to convince utilities.

6.4.4 Scale Up

Two of the utilities contacted emphatically expressed that they would not be able to invest in a 400 MW commercial plant on the basis of data from a 10-20 MW pilot demonstration. They have the experience of frequent failures on scale up factors of this magnitude from all sorts of unanticipated technical, mechanical, environmental and financial problems. As a result, they have a "show-me" attitude.

6.4.4 Scale Up (Continued):

The third utility expressed a position that if a 10-20 MW feasibility plant were to show trouble-free operations they might be willing to commit to a full scale plant. They would, however, feel more comfortable going from the 25-50 MW trouble-free demonstration to a 100 MW commercial plant. Since 400 MW was defined in this study as the commercial plant, scale up from a 10-20 MW would not satisfy the utilities.

6.5 Summary

As shown above, there was considerable concern about not only the engineering and technology risks associated with the hull, position keeping and CWP, but also concern about the technology of the interface requirements needed to make the entire system operate efficiently and reliably. Perhaps the greatest concern was the ability of the OTEC plant to fit into the individual utility's expansion needs, capital structure, and system infrastructure-interface requirements.

6.6 Conclusion

The conclusion reached from the electric utility survey is that a Demonstration Plant would have to be constructed, deployed, and operated as part of an existing power grid for at least a year in order to provide the operational data necessary to support individual investments by electric utilities. Further, the Demonstration Plant should not be a scale model, but a full scale plant in every respect. This raises the issue of what is full scale. In this study, full scale has been selected as 400 MW based on the benefit-cost analysis of preliminary concepts of plants either singly sited or sited in groups of eight. Lacking further guidance, a demonstration with full scale components would be recommended. A market study to determine the optimum plant size and the number of potential units is also recommended. It is suggested that plant size is highly dependent on grid access, the ratio of OTEC power to local shore power, and the grid capability to respond to an unscheduled OTEC outage. These considerations are discussed in the next section.

7. MARKET ASSESSMENT

7.1 Introduction

As shown in Section 4, the Ocean Systems side of the Gibbs & Cox, Inc. team is confident that an OTEC Platform of any reasonable size can be built to meet Top Level Requirements. Also as previously shown, the utility executive is a pragmatic businessman, interested not only in the financial and engineering factors, but in how the OTEC Plant fits his needs. This opens up a wide range of thought on OTEC marketability.

7.2 Basic Market

Discussions with utility executives indicate more attention should be paid to what size is economically feasible to utilities rather than what size is the most cost effective based on the best combination of Hull/Ocean System, Power and Transmission System, and siting environment. This market risk may be the most important part of both the demonstration unit size and the size of the commercial plant.

There is probably a large market in tropical areas today that could use an OTEC Plant in the 10 - 25 MW range. For instance, Reference (1) reports the U. S. Territory of Guam has contracted with a Japanese firm to build a "sea-thermal" power plant sized at 10 MW. In many of these applications the OTEC Plant might be the major or only significant power source available, and places where electric power could be priced to make the OTEC unit a desirable investment. Power grid matching would not be a requirement in these cases. The market for a 100 MW sized commercial plant which might be available by 1985 to 1990 is less defined. Applications in this range would probably be in areas where the OTEC Plant would fit in with the expansion plans of the utility concerned and where initial applications should not be more than 5 - 15 percent of the then currently installed capacity. Typical applications might be Puerto Rico or Oahu, Hawaii.

The market factors relating to the Keahole Point, Hawaii site assigned to Gibbs & Cox, Inc. and the above is illustrative. Particularly, the installed utility capacity on the island of Hawaii is about 100 MW which operates to deliver a little over 50 MW average power. If installed today, a 25 MW OTEC base-loaded plant would generate half of the power requirements of this island. At a demand growth rate of six percent per year, a 100 MW OTEC Plant would generate half of the

7.2. Basic Market (Continued):

power requirements in 1990. Similarly, off the island of Oahu a 25 MW OTEC plant added to the 1200 MW installed capacity would be adding only four percent to the average power generation. Since plant additions are being made and planned at the 150 MW range in the near future and 200 MW range by 1985, a 200 MW plant would provide a reasonable fit in the 1985-1990 time frame. A 100 MW plant with add-on capability would also make sense, and a 400 MW plant if introduced in a timely manner would fit the Oahu growth requirements, since by 1990 the installed capacity would be close to 2200 MW. The 400 MW OTEC plant would be a reasonable growth increment 1990 or later, at a reasonably small fraction of total capacity.

The market for an OTEC plant in the 400 MW range and the envisioned energy parks in the 3200 MW range have even a more restrictive market. They could be used as additions to the Continental U. S. power grid provided load adjustments could be made in case of total OTEC power failure. The 400 MW OTEC plant would be compatible with the planned coal fired plants that are being installed in the 400-700 MW range. The 3200 MW plant park would be compatible with most nuclear plants which are being installed in the 1000-1200 MW range (Reference (2)).

An interesting sidelight to the utility point of view is that they are accustomed to dry land operations and that the floating plant and manning will be a foreign operation for them. For this reason, the utilities will probably prefer to see small power plant size applications first with subsequent larger units installed in a pattern similar to the growth of the nuclear power industry.

7.3 Other Market Considerations

The cost of building, deploying, testing and demonstrating an OTEC Demonstration Plant is substantial. Since it will be built to specifications which require a 40 year life, there is a little more latitude in sizing a Demonstration Plant than the utility might be aware. If the Federal Government builds a Demonstration Plant and if it is technically successful and if switching and grid compatibilities can be arranged, the utility can reduce fuel consumption at current plants as an offset to OTEC operating costs and make money. At this time it would be reasonable to consider not only the potential return from providing electric power

7.3 Other Market Consideration (Continued):

during the test period, but to further consider a continuing operation of the plant after the demonstration. This consideration would tend to drive the demonstration unit to the largest size because of economies of scale and the potential for displacing oil as a fuel.

Based on electric power plant consumption of oil at 1.15×10^6 tons (Reference (3)) (0.16×10^6 barrels) per year per 1000 MW at 60 per cent utilization and a cost of oil at \$96/ton, a savings in fuel cost of \$184,000/MW/Yr. would accrue if an OTEC plant displaced power from an oil fired electric plant. The following is a representation of fuel savings at 90 percent utilization of the OTEC plant:

<u>PLANT SIZE</u>	<u>ANNUAL FUEL SAVINGS</u>
25 MW	\$ 4.1 M
50 MW	8.3 M
100 MW	16.7 M
400 MW	66.2 M

From Reference (4) the plant operating costs can be roughly approximated as

$$C_{op} = 1.8 + .025 \times MW$$

Where:

$$\begin{aligned} C_{op} &= \text{OTEC plant operating costs (\$M)} \\ .025 &= \text{size cost factor (\$/MW)} \\ MW &= \text{plant electrical output} \end{aligned}$$

Figure 7.3-1 is illustrative and shows fuel savings exceeding operating costs at about 25 MW. This would be the lowest possible size to consider from this point of view as other system associated costs have not been considered and costs are often underestimated in larger projects of this type. Therefore, applying a risk factor of three times estimated costs, a 100 MW range plant would be recommended.

Furthermore, on the basis of \$.055/KWH average retail price of electricity in Hawaii, revenue based on a 90 percent utilization factor would be \$433/KW-Yr. The following is representative of 100, 50 and 25 percent load factors:

FIGURE 7.3-1

COST TO OPERATE VS. FUEL SAVINGS (BASED ON VOLUME II DATA)

FIGURE 7.3-2

COST TO OPERATE VS. REVENUE @ \$.055/KWH
HAWAII SITE. (BASED ON VOLUME II DATA).

7.3 Other Market Consideration (Continued):

<u>PLANT SIZE</u>	<u>REVENUES (\$M)</u>		
	<u>LOAD FACTOR</u>		
	100%	50%	25%
25 MW	12	6	3
50 MW	24	12	6
100 MW	48	24	12
400 MW	96	48	24

Even at low load factors and no fuel savings the very small OTEC plants would be economical to operate as shown in Figure 7.3.2. The same risk factor of three times estimated costs should be applied which would allow a break even choice of a 50 MW plant at 50 percent load factor or a 100 MW plant at 25 percent load factor.

A point to be made is that a Demonstration Plant financed by the government has an immediate pay off to the utility as a fuel displacer even if the capacity is not needed. The plant could immediately commence operations at full utilization whereas in the normal case a period of low utilization is matched to growth needs. For these reasons, a larger plant is favored up to a size when the utility could handle the load switching in case of OTEC failure.

Another point to remember from Reference (4) is that due to volume and weight relationships, the OTEC economies of scale are significant up to the 100 MW level and were relatively constant in the 100-500 MW range. The change in concept from internally mounted heat exchangers to externally mounted heat exchangers might alter the slope of the relationship but should not alter the general shape. Therefore, on an economy of scale basis a 100 MW plant would be the minimum commercial size for significant economical additions to existing grids.

8. DEMONSTRATION PLAN

8.1 Introduction

There are four viable alternatives to the solution of Demonstration Plant size. The alternatives depend somewhat on when DOE feels the task of developing Ocean thermal power is complete and when the utilities feel they can safely proceed on their own. They also depend on the potential market.

The first alternative to demonstrate economic viability to utility users is to build the 400 MW hull and CWP combination with 400 MW of installed power. This has the advantage of proving all aspects of the plant and virtually eliminating technical and cost risk. It has the further advantage of using the same shipyard and production tooling; it takes full advantage of learning curve economies; it is compatible with the energy park goal of 3200 MW; and, it puts DOE in the best position, having demonstrated the objective size. However, it is the most expensive, time-consuming option.

The second alternative is to build a 400 MW hull and cold water pipe, but install only 100 MW of power system initially. Then, as the 100 MW system is proved, have the utility take over and add to the plant to achieve the 400 MW capability. This approach would provide adequate proofing of the plant at about one-half the cost to the government. It would accomplish the same objectives in about the same time. Subsequent plants could also use the same shipyard, production tooling, and facilities. The basic difference between this alternative and the basic full size alternative is the allocation of the financial burden.

The third alternative is a 100 MW scaled hull with scaled CWP but one which uses full scale power system components. This alternative could be built in the same form as the larger plant, and the production equipment might be made sufficient for the follow on requirements. This size of plant has the advantage of bridging the gap between the 10-20 MW pilot plant and the 400 MW commercial plant. It would cost less than the 400 MW hull/100 MW power system alternative and would probably stand alone as a commercial plant itself fitting a particular market. This plant would provide adequate data with which analyses of utility investments could be conducted. However, there is always the chance that it

8.1 Introduction (Continued):

might not be cost-effective for utilities, and investments in larger plants may require subsidies or government cost sharing.

The fourth alternative is for the government not to build a commercially viable Demonstration Plant but to rely on the results of the 10-20 MW pilot plant to generate interest in plants of the 10-20 MW size. Then as the market is developed through success at these levels, induce utilities to invest at whatever subsidy and cost sharing arrangement is appropriate at the time.

Since the requirement is to recommend a Demonstration Plant size, Gibbs & Cox, Inc. recommends a 100 MW plant using full sized (50 MW) Commercial Plant modular components to the maximum extent possible. This would require two 50 MW modules of the turbine, generator, and heat exchangers as envisioned for the larger plants. The hull and cold water pipe would be sized to accommodate these components at appropriate water flow rates. This recommendation is a synthesis of all the information available to the team at this time.

8.2 Recommended Plant-Ship

For the ship option, a 100 MW barge-shaped hull approximating the proportions of the Commercial Plant ship is recommended. Either new construction or conversion would be possible, depending on anticipated plant life and economic evaluation. A concept is presented in Section 8.5 which utilizes new construction. An alternative, using an existing tanker with adequate beam and depth (approximately 2000,000 tons deadweight), would also be adequate.

8.3 Recommended Plant-Semi-Submersible

If the semi-submersible configuration is selected for the Commercial Plant, several options are available. First, a ship-type platform would appear to be adequate, since the difference in performance between a ship and a semi-submersible platform can be predicted analytically. Therefore, the results of demonstration on a ship-type platform should be sufficient for both the Ocean Systems and powerplant communities. Alternatively, an existing semi-submersible could be converted for the mission. Studies related to the OTEC-1 program

8.3 Recommended Plant-Semi-Submersible (Continued):

indicate that a large (40,000 ton) semi-submersible drill rig could be converted to support up to 100 MW (2-50 MW modules) using external heat exchangers in a configuration similar to the Gibbs & Cox, Inc. design. This is discussed in Section 8.6. However, as noted in Section 4.2.1, the use of a semi-submersible is not essential, and should only be used if it is not significantly more expensive.

8.4 Demonstration Site

As previously shown, a 100 MW addition to the island of Hawaii at Keahole Point would provide one half of the electric power base predicted in 1990 and 100 percent of the average load. It is questionable whether or not the demonstration unit could be tested at full power, which is a requirement.

The use of Keahole Point also requires the acquisition of land and the construction of shore facilities including housing. The logistics associated with this site will further add to the costs not only of demonstration but to follow-on operational costs as well.

Conversations with Dr. Yoshihara, the energy coordinator for Senator Matsunaga of Hawaii, have lead to a recommendation to do the OTEC demonstration at Barbers Point, Oahu; about 15 miles from Honolulu. This site has the advantages of:

- Providing for use of the full 100 MW capacity
- Local power grid access
- Serving an industrial park
- Simplified logistics
- Visibility and access
- Lower cost to demonstrate and to operate
- Availability of personnel

Figure 8.4-1 is a partial reproduction of a nautical chart of the area with a 500 fathom (3000 ft) contour drawn. The nearest point to shore would be approximately

8.4 Demonstration Site (Continued):

three miles. Slopes of the bottom contour are as shallow as Keahole Point. An environmental site survey would be required to determine the exact location and due consideration must be given to other activities in the area.

8.5 Demonstration Plant Design - Ship

The recommended ship-type Demonstration Plant consists of a hull nominally 390 x 170 x 85 feet, displacing 82,000 tons, and a CWP nominally 50 x 3000 feet. Figures 8.5-1 - 8.5-4 provide conceptual design of the hull including arrangements of major equipments. The arrangements are slightly less efficient than those in the 400 MW plant due to the relationships of the two 50 MW modules to the centerline CWP. Design practices and specifications are the same as those detailed in Task V, Volume II of this report. A summary of the 100 MW Demonstration Plant weight estimate is shown in Figure 8.5-5.

8.5.1 Construction and Deployment

8.5.1.1 Hull

The hull for the 100 MW Ship Demonstration Plant will be constructed as a single unit in its normal orientation as contrasted to the split hull approach for the 400 MW commercial hull. The machinery and equipment which can be installed within the hull will be installed in dry dock or pier side after launch. The heat exchangers and sea water discharges, will be installed offshore where the water depth is approximately 400 feet.

Upon completion of total outfitting and appropriate checkouts, the platform will be towed to the Barbers Point, Oahu site.

8.5.1.2 Cold Water Pipe

The cold water pipe will be constructed of pre-formed/rolled steel plate with appropriate stiffeners similar to that described in Volume II. Sections will be semi-circular and 50 feet long. They will be transported as space permits on the platform or by barge to the site.

FIGURE 8.5-1

OTEC DEMONSTRATION PLANT: INBOARD PROFILE (SHIP)

FIGURE 8.5-2
 OTEC DEMONSTRATION PLANT - PLAN VIEW - UPPER LEVEL (SHIP)

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FIGURE 8.5-3
 OTEC DEMONSTRATION PLANT: PLAN VIEW - LOWER LEVEL (SHIP)

FIGURE 8.5-4
OTEC DEMONSTRATION PLANT: SECTION LOOKING AFT (SHIP)

FIGURE 8.5-5
SUMMARY OF WEIGHT ESTIMATES (SHIP)

WBS GROUP	WEIGHT (TONS x 10 ⁻³)
1.0 PLATFORM SYSTEM	44.4
2.0 CWP SYSTEM	16.5
3.0 POWER SYSTEM	20.0
4.0 ENERGY TRANSMISSION SYSTEM	0.6
5.0 OPERATIONAL SUPPORT	0.5
TOTAL DISPLACEMENT INCLUDING 10% MARGIN	82.0

18351-10 (W-10,020)

8.5.1.2 Cold Water Pipe (Continued):

Assembly of the CWP will commence on site prior to arrival of the platform at a rate to obtain the most expeditious completion of the complete plant.

The concept of assembly is the same as that described in Volume II, except that the specially designed CWP construction barge will be proportionately smaller.

8.5.1.3 Position Keeping

It is assumed that the wind and sea conditions are the same at Barbers Point as at Keahole Point. Since the effective drag of the Demonstration Plant is approximately one-half that of the 400 MW Commercial Plant and the water depth and bottom slopes are approximately the same, it is concluded that the position keeping performance requirements are one-half of the Commercial Plant. Thus, 7 sets of anchors, chains, pendant buoys, etc. will be required for the demonstration unit vice 14 required for the 400 MW plant.

8.5.2 Cost and Schedules

8.5.2.1 Cost Estimates

Cost estimates were proportioned from those in Volume II for the Commercial Plant. A summary of the cost data is provided in Figure 8.5-6. The total cost of the Demonstration Plant including deployment and operations for a period of one year is \$304M. Cost estimates do not include procurement costs for Power System or Transmission System components.

8.5.2.2 Schedule Estimates

An overall schedule of major events is shown in Figure 8.5.7. The schedule shows 12 months for a contract Design, 24 months for detail design and construction, 3 months for deployment and on-site assembly and 15 months for test and evaluation. A three-month bid evaluation period is also included in the Contract Design schedule.

FIGURE 8.5-6
OTEC DEMONSTRATION PLANT COST SUMMARY (SHIP)

<u>WBS GROUP</u>	<u>TITLE</u>	<u>TOTAL PROGRAM COST, \$M</u>
1.0	Platform System	196.4
2.0	Cold Water Pipe System	44.0
3.0	Power Systems	7.3
4.0	Energy Transfer Systems	2.0
5.0	System Engineering & Integration	5.4
6.0	System Test & Evaluation	7.3
7.0	Operational Support	13.8
8.0	Deployment Systems & Services	10.8
9.0	Industrial Facilities	10.0
10.0	Environmental, etc.	0.7
11.0	Project Management	6.0
		<u>\$ 303.7 M</u>

FIGURE 8.5-7 OTEC DEMONSTRATION PLANT SCHEDULE ESTIMATE - SHIP (NEW CONSTRUCTION)

8.5.3 Logistics Support

Elements of the logistic support function are included based on the data in Volume II. The principal difference between the 100 MW Demonstration Plant at Barbers Point and the 400 MW commercial unit at Keahole Point, is that facilities and support will be leased or rented for the required period rather than acquired and constructed. Furthermore, the logistic support distances are reduced by a factor of 10 from Honolulu as a base.

8.5.4 Operations

Operations costs are assumed to be about one-half those of the 400 MW commercial plant, since the smaller size the platform is offset by the fact that manning levels would not be appreciably lower, based on OTEC-1 estimates.

8.6 Demonstration Plant Design - Semi-Submersible

Figure 8.6-1 through 8.6-4 illustrate a possible concept for a 100 MW semi-submersible Demonstration Plant, based on conversion of an existing drill rig of 40,000 tons displacement. The special rig is ODECO's "OCEAN RANGER", which appears well suited for the mission since it was recently constructed and is adequate in size to support the required payload. Other platforms of this type and configuration are also available, but the "RANGER" is considered typical of the large, very stable drill rigs now in service throughout the world, operating in such hostile environments as the North Sea, Gulf of Mexico and Gulf of Alaska.

The illustrated concept installs two 50 MW commercial plant modules with all seawater components and the heat exchangers below the operating (80 foot) waterline. This configuration takes maximum advantage of the buoyancy of the heat exchangers to reduce the impact of the installation on the weight-sensitive drill rig. The turbines and generators, power conditioning equipment and related support are all located on the upper cross structure. This necessitates the removal of the derrick, drawworks, pipe storages, and other topside gear other than mooring and accommodations. The existing mud pumps and mud stowage facilities could be removed, as well as the blowout preventer and other oil drilling-related gear. The weight saved by these removals will compensate for the net increase of approximately 5,000 tons resulting from the OTEC 100 MW loop installation. The total added system

FIGURE 8.6-1
100 MW SEMI-SUBMERSIBLE DEMONSTRATION PLANT: ELEVATION

FIGURE 8.6-2

100 MW SEMI-SUBMERSIBLE DEMONSTRATION PLANT : PLAN - LOWER HULLS

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FIGURE 8.6-3
100 MW SEMI-SUBMERSIBLE DEMONSTRATION PLANT: PLAN - UPPER DECK

FIGURE 8.6-4
100 MW SEMI-SUBMERSIBLE DEMONSTRATION PLANT; SECTIONS

8.6 Demonstration Plant Designs Semi-Submersible (Continued):

weight (exclusive of seawater) is about 18,000 tons. However, this is offset by the buoyancy of the heat exchangers, vapor pipes and other added appendages as well as the removals noted above. In this specific design, the 50 foot diameter CWP must be neutrally buoyant. The total molded displacement including heat exchangers, pumps, plenum, vapor pipes and water tight structure is approximately 75,000 long tons in this condition, about twice that in the existing drilling condition. Figure 8.6-5 indicates the weight changes associated with this concept.

The configurations illustrated would utilize a neutrally buoyant CWP. Existing ballast tanks could be used for ammonia storage unless separate external tanks proved more cost effective. The existing mud storage area would be available for auxiliary equipment. Existing propulsion, mooring, auxiliary, control, and habitability systems would be essentially untouched by the conversion.

The estimated cost for the entire program, including one year of demonstration, is indicated on Figure 8.6-6. The Platform System costs reflect conversion of the rig to support the 100 MW payload, and exclude equipment costs for the Power and Energy Transfer Systems. Costs for WBS 5.0 through 11.0 reflect the 100 MW ship Demonstration Plant costs discussed earlier. A typical charter rate of \$40,000 per day is indicated, resulting in a \$36 M leasing charge for the total period of platform availability. This charge would have to be traded off against the cost of out right purchase of the platform.

The estimated schedule for the Demonstration Plan using a converted semi-submersible drilling platform is about 45 months versus 54 months for the new construction ship platform. This 9 month savings reflects shorter fabrication/construction time. It can be assumed that a new construction semi-submersible would involve a total schedule approximately the same as the ship.

WEIGHT CHANGES - 100 MW SEMI-SUBMERSIBLE

<u>ITEM</u>	<u>WEIGHT, L. Tons.</u>
Existing Full Load	39,000
<u>Deductions:</u>	
Derrick, Drawworks, other topside outfit	600
Drill Water, Dry Mud, Cement, Liquid Mud	4,600
BOP, Mud Pumps, Cement Tanks, Misc.	<u>1,000</u>
NET:	32,800
<u>Additions:</u>	
Deckhouse Structure, fdns	1,200
Heat Exchangers (Dry Weight)	7,670
Seawater Pumps, Shafting, Motors	2,240
Turbo-Generators	530
Demisters	800
SW Piping	260
NH ₃ System and Piping	1,520
Intake Screens, Discharge Ducts	90
CWP (Neutrally Buoyant)	500
Power Conditioning	530
Miscellaneous Outfit	<u>500</u>
Equipment Sub-Total:	15,800
NH ₃ in System	930
Water in Heat Exchangers	7,370
Water in SW Piping, Pumps	<u>18,500</u>
	42,640
CONVERTED DISPLACEMENT*	75,440

*Excludes water in CWP, discharge ducts.

FIGURE 8.6-6

TOTAL PROGRAM COSTS - 100 MW SEMI-SUBMERSIBLE DEMONSTRATION PLANT

<u>WBS GROUP</u>	<u>TITLE</u>	<u>TOTAL PROGRAM COST, \$M</u>
1.0	Platform System	
	• Removals	2
	• New Structure, Fdtn.	4
	• New Platform Systems, Outfit	10
	• Seawater System	<u>40</u>
	Sub-Total	56
2.0	Cold Water Pipe System	40
3.0	Power Systems	5
4.0	Energy Transfer Systems	2
5.0	System Engineering & Integ.	3
6.0	System Test & Evaluation	7
7.0	Operational Support	13
8.0	Deployment Systems, Services	2
9.0	Industrial Facilities	10
10.0	Environmental, etc.	1
11.0	Project Management	<u>6</u>
	Sub-Total:	\$ 145 M
	Platform Leasing Charge @ \$40 K/day with 2-1/2 year construction/operation:	<u>36 M</u>
		\$181 M

9.0 Conclusions and Recommendations

The following conclusions and recommendations should be viewed in light of the objective and the constraints discussed previously. The objective of the demonstration is to convince electrical utilities of the technical and economic viability of OTEC. With this in mind the following conclusions are reached:

1. Assuming successes in the OTEC program through the 10 to 20 MW Pilot Plant phase, there should be no insurmountable ocean engineering or naval architectural problem in building, deploying and operating a 400 MW commercial plant.
2. Utility executives are pragmatic businessmen working in a capital-intensive industry where accurate, reliable data will be required in order to ensure their required return on investment.
3. Risks in scale-up of components and system integration are known and feared by utilities; therefore a demonstration unit should use full scale components operating under the same conditions as they would on a 400 MW commercial plant.
4. The smallest unit required to demonstrate economic viability to utility users of a 400 MW commercial OTEC plant is a 100 MW plant using 50 MW commercial plant modular components.
5. OTEC commercial plants will have to be sized to fit the market, i.e., the needs of the user. This requires consideration of existing capacity, load factors, growth rates, load switching capabilities.
6. Because of market and logistic factors, a site off Barbers Point, Oahu is recommended for the 100 MW demonstration unit vice the site off Keahole Point, Hawaii.
7. OTEC plants, once on line, can be operated at maximum rates because of existing capacity fuel offset.