OCEAN THERMAL ENERGY CONVERSION (OTEC)
TEST FACILITIES STUDY PROGRAM

Final Report, Volume I

MASTER

January 17, 1977

Work Performed Under Contract No. E(04-3)-1156

Lockheed Missiles and Space Company, Incorporated
Sunnyvale, California

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161

Price: Paper Copy \$12.50 (domestic)

\$15.00 (foreign)

Microfiche \$3.00 (domestic)

\$4.50 (foreign)

OCEAN THERMAL ENERGY CONVERSION (OTEC) TEST FACILITIES STUDY PROGRAM

VOLUME I

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

FINAL REPORT

Prepared by

OCEAN SYSTEMS

LOCKHEED MISSILES & SPACE COMPANY, INC.

SUNNYVALE, CALIFORNIA 94088

17 JANUARY 1977

PREPARED FOR UNITED STATES

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

DIVISION OF SOLAR ENERGY

UNDER CONTRACT NO. E(04-3)-1156

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

FOREWORD

Lockheed Missiles & Space Co., Inc. and its team members have completed an 8-month study to develop alternative non-site-specific OTEC facilities/platform requirements for an integrated OTEC test program which may include land and floating test facilities. The study was performed for the Energy Research and Development Administration (ERDA) under Contract E(04-3)-1156 initiated with a kick-off meeting on 8 January 1976.

This document is Volume I of a two-volume final report. It provides updated copies of the visual aids and a summary of the oral presentation given to ERDA representatives on 26-27 August 1976 at Sunnyvale, California. Volume II, a three-part appendix, is a compendium of the most significant detailed data developed during the study. For convenience of the reader, the principal parts and sections of Volume II are listed below:

Part A	1 Definitions
	2 Baseline Revisions
	3 Test Plans
	4 Energy Utilization
Part B	5 Annotated Test List
	6 Component Tests
	7 Systems Tests
Part C	8 Test Facility Support
	9 Data Acquisition and Control System
	10 Cost Data
	11 Energy Self Sufficiency
	12 Test Facility Applications

CONTENTS

Section	Page
A. Program Overview	A-1
B. Baseline Configuration	B-1
C. Test Plans	C-1
D. Energy Utilization	D-1
E. Scaling	E-1
F. Testing I Requirements	F-1
G. Testing I Test Beds	G-1
H. Testing II Requirements	H-1
I. Testing II Landbased Cycle Plant	I-1
J. Testing II Landbased Test Facility	J-1
K. Testing II Seabased Cycle Plant	K-1
L. Testing II Sea Based Test Facility	L-1
M. Data Acquisition and Control System	M-1
N. Cost Summary	N-1
O. Schedule Summary	O-1
P. Conclusions	P-1

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

SUMMARY

A comprehensive test program has been envisioned by ERDA to accomplish the OTEC program objectives of developing an industrial and technological base that will lead to the commercial capability to successfully construct and economically operate OTEC plants. This study was performed to develop alternative non-site specific OTEC test facilities/platform requirements for an integrated OTEC test program including both land and floating test facilities.

A progression of tests was established in which OTEC power cycle component designs proceed through advanced research and technology, component, and systems test phases. This progression leads to the first OTEC pilot plant and provides support for following developments which potentially reduce the cost of OTEC energy. It also includes provisions for feedback of results from all test phases to enhance modifications to existing designs or development of new concepts. The tests described in the report should be considered as representative of generic types since specifics can be expected to change as the OTEC plant design evolves. Emphasis is placed on defining the test facility which is capable of supporting the spectrum of tests envisioned.

As a basis for system test requirements, the April 1975 LMSC baseline thermal cycle was refined principally by adjustment of warm and cold water flows and cold water pipe length. The improved gross output of 91 MW_e per power module provides a net output from a four-module plant of 264 MW_e. Power cycle system tests can be performed in a land-based cycle plant, sized at 3 MW_e due to limits imposed by available warm water resources, or in a 6 MW_e sea-based cycle plant, which is estimated to provide results which can be extrapolated to full scale and which can be carried by a range of candidate sea-going platforms. Both alternatives are suitable for testing various configuration power cycle components and supporting the full range of tests necessary to verify cycle plant operation including principal auxiliary systems.

Component testing is primarily concerned with heat exchangers, turbines, sea water pumps, and platform internal hydrodynamics, as these items exert a primary effect on OTEC energy cost. Component test model scaling effects are discussed and, following the guidance that testing at an ERDA dedicated facility be done only if existing facilities are inadequate, yield test arrangements for heat exchangers of 100,000 BTU/sec capacity and turbines and pumps at 1/5 linear scale (1/25 capacity). The component test arrangements are such as to accommodate various external and internal configurations within a given envelope and mating interface. Closed loop flow of ammonia and water is used extensively to accomplish larger scale testing within reasonable energy resource limits. Both cycle plant and component test beds were sized and designed to accommodate alternative component configurations suggested by the various OTEC power plant investigators.

Heat transfer enhancement, biofouling control, and innovative energy utilization methods account for most of the anticipated advanced research and technology testing (AR&T). It is concluded that these tests should be done in existing university, commercial, or government laboratories. Space and operating costs have been allotted in the ERDA dedicated facility for the few tests which support specific investigations or are not within the purview of existing facilities.

Limited Engineering Development testing will be required as a part of the effort to produce the first OTEC demonstration plant, to verify design assumptions, and/or to provide specific values for operating parameters. This testing, in support of engineering and entirely within the current state-of-the-art, is not within the definition of AR&T or component testing. Engineering Development testing includes items such as measurement of heat transfer parameters for the baseline configuration and measurement of performance of existing turbines with wet ammonia vapor. Engineering Development activities were not included in the test facility requirements.

Electrical power, hydrogen, and ammonia were shown to be technically feasible as means for transmitting OTEC power to a land-based distribution point. Cost of OTEC electricity connected to an on-shore grid was shown to be marginally competitive with on-shore-produced electricity when the OTEC plant is near shore and increasing in cost

as the OTEC plant distance from shore increases. The cost of OTEC produced hydrogen and ammonia were shown to be not competitive with current prices. Space can be provided within the platform to house the required equipment and to allow safe operation of the equipment. Testing requirements are defined for electrical and pipeline transmission equipment, to verify operation of hydrogen and ammonia plants on board the platform, and to demonstrate feasibility of innovative energy utilization techniques.

All test support facilities and equipment have been identified and included in terms of space, utilities, cost, schedule, and constraints or risks. A highly integrated data acquisition and control system has been included to improve test operations and facility effectiveness through a centralized computer system capable of automatic test control, real-time data analysis, engineering analyses, and selected facility control including safety alarms.

Construction and mobilization costs and schedules have been generated for the various cycle plant and component test bed arrangements. These costs and schedules have been integrated with test facility support and personnel to provide lifetime cost estimates.

The ERDA Statement of Work states "The effort under this contract, therefore, is limited to the development of information and data on alternative test facility requirements and only to such depth as needed by ERDA for test planning. The development of data or recommendations as to site specific test facilities or specific candidate sea-test platforms is not within the purview of this contract." Therefore no specific conclusions or recommendations are presented in this report.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

INTRODUCTION

This report contains the results of an 8-month study to define test facility requirements which will support the Ocean Thermal Energy Conversion (OTEC) integrated test program. These results were presented to Energy Research and Development Administration (ERDA) representatives on 26-27 August 1976. The subjects contained herein and their section ordering are the same as that given at the presentation. The material has been updated by a few additions covering subtasks not completed at the time of the presentation and by corrections to the presentation material. In addition, a three part appendix which provides the most significant detailed data has been included.

Each of the 16 sections of Volume I of the report is introduced by a subject page followed by a list of section contents or a discussion of topics, either of which summarizes the section. The contents of the report are presented using the updated visual aids from the August oral presentation, accompanied on the facing page by a brief text which summarizes the material presented. As an aid to reading the report, the table below relates the sections of the report to the tasks of the Statement of Work.

<u>Work Statement Task</u>	<u>Report Section</u>
A. ESTABLISHMENT OF SYSTEM TEST REQUIREMENTS	
A.1 Baseline Review	B, App. 2
A.2 Range of Plausible System Tests	C, H, N, App. 5
A.3 Component Scaling	E
A.4 System Trade-offs	E, H, I, K, O
A.5 System Test Configuration	I, K, App. 7
A.6 System Test Plans	C, App. 3
B. ESTABLISHMENT OF COMPONENT TESTING REQUIREMENTS	
B.1 Component Testing Delineation	F, App. 3, 5, 6
B.2 Test Beds	G, App. 6
C. ADVANCED RESEARCH AND TECHNOLOGY (AR&T) REQUIREMENTS	
C.1 Potential Experiments	F, App. 5
C.2 Test Beds	C, F

Work Statement Task

Report Section

- D. ESTABLISHMENT OF ENERGY UTILIZATION REQUIREMENTS
- E. ESTABLISHMENT OF TEST FACILITY SUPPORT REQUIREMENTS
- F. SYSTEM ANALYSIS

D, App. 4

J, L, M, App. 8. 9

J, L, N, O, P,
App. 10, 11, 12

OTEC PROGRAM OVERVIEW

PRESENTED BY
LLOYD C. TRIMBLE

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

PROGRAM OVERVIEW

Study team

Study ground rules

Study tasks

Testing categories

Test requirements

STUDY TEAM

LMSC _____ PRIME— SYSTEMS DEFINITION & INTEGRATION

BECHTEL _____ FACILITIES DESIGN, COST, AND UTILIZATION DESIGN

SRI _____ ENERGY MARKET ANALYSIS

STUDY TEAM

The contract for the performance of this study was awarded to LMSC, who established the requirements, prepared the definition, and integrated the results. Using the requirement established by LMSC, Bechtel Corporation prepared facilities design concepts, which were subsequently reviewed and approved by LMSC, and the cost estimates and schedules for facilities construction. SRI participated by conducting the energy market analysis for electricity, hydrogen, and ammonia production requirements through the year 1995 for the southeastern U. S.

STUDY GROUND RULES

PRIMARY OBJECTIVES ARE TO DETERMINE TEST FACILITIES

- REQUIREMENTS
- COSTS
- SCHEDULES

TEST FACILITIES DEFINITION ARE BASED UPON

- UPDATED LMSC POWER CYCLE BASELINE
- POWER CYCLE SYSTEMS COMPONENTS, AR&T AND ENERGY UTILIZATION ONLY
- ALTERNATIVE POWER CYCLE SYSTEMS & COMPONENTS

LAND- AND SEA-BASED CONCEPTS TO BE EVALUATED

ACQUISITION OF LAND/PLATFORM IS EXCLUDED

CONCEPTS ARE SITE/PLATFORM INDEPENDENT

STUDY GROUND RULES

The ERDA statement of work identified the effort of this study to be "limited to the development of information and data on alternative test facility requirements and only to such depth as needed by ERDA for test facility planning." Most of the material presented falls within this definition. The task entitled "Establishment of Energy Utilization Requirement" exceeded this definition slightly. Generally, the objectives identified here are slanted in the direction of fulfilling the goals of the effort.

The facilities should be designed to accommodate components and systems conceived by others as well as those conceived by LMSC. It should be sufficiently flexible to accept future generations of components and systems and to conduct advanced research and technology experiments.

A-7

The study is to evaluate both land- and sea-based test concepts, but is to be independent of specific geographical locations and specific sea-based platforms.

STUDY TASKS

- A. ESTABLISH SYSTEM TEST REQUIREMENT
- B. ESTABLISH COMPONENT TEST REQUIREMENTS
- C. ESTABLISH AR&T REQUIREMENTS
- D. ESTABLISH ENERGY UTILIZATION REQUIREMENTS
- E. ESTABLISH TEST FACILITY SUPPORT REQUIREMENTS
- F. SYSTEM ANALYSIS LEADING TO TEST FACILITIES REQUIREMENTS

STUDY TASKS

The tasks to be accomplished under the contract were specific as to title but general as to the detail of description. This provided sufficient latitude for LMSC to examine a relatively broad spectrum of requirements under each task heading.

Early in the study it became apparent that one additional task must be performed, i.e., an assessment of available thermal resources on land. The rationale for this task is that it would have been a completely useless exercise to prepare facility concepts without benefit of knowing what might be a practical limit on the maximum size system or component that could be tested with available thermal resources. To this end, a brief survey was conducted to determine typical resources, but no recommendation is made as to which site should be used.

TESTING CATEGORIES

- ENGINEERING DEVELOPMENT
- AR&T
- COMPONENTS
- SYSTEMS

TESTING CATEGORIES

Four categories of testing have been established in support of conducting the OTEC Test Facilities Study Program. These four categories are Engineering Development, Advanced Research and Technology, Component, and Systems. The category "Engineering Development", in addition to the other three which are identified in the Statement of Work for the Test Facilities Study Program, is necessary to complete the definition of an integrated test program for OTEC plant development. The definition of each category as used herein is given below.

"Engineering Development Tests" are those which validate assumptions used in the OTEC plant and its components performance analysis. It includes the identification and resolution of potential problem areas through the manufacturing process definition phase.

"Advanced Research and Technology Tests" are those tests normally conducted on parts or pieces of components or assemblies to advance the state-of-the-art from a time-framed baseline and which lead to a cost reduction of OTEC energy.

"Component Tests" are those tests which determine component performance under controlled conditions. Component tests provide confidence to proceed to the next development stage such as cycle plant or pilot plant. To derive test facility requirements, components to be tested at the test facility are those which cannot be adequately defined by a performance/design specification; or vendor test capability is inadequate to demonstrate specification compliance; or the test can be conducted at minimum cost at the test facility; and the performance verification is significant to carrying the program forward.

"Systems Tests" are the power cycle performance tests utilizing a cycle plant arrangement. System tests confirm validity of power cycle assumptions, determine component interactions, and provide the confidence to proceed to a full-scale power cycle or module.

TEST REQUIREMENTS

- CONDUCT/PERFORM TESTS AND EXERCISES TO DEMONSTRATE TOTAL OTEC PLANT CAPABILITY
- EVALUATE ALTERNATE OTEC COMPONENTS, SUBSYSTEMS, AND SYSTEMS IN A LOGICAL AND ECONOMICAL MANNER
- ASSIST IN ADVANCING OTEC COMPONENT/PROCEDURAL STATE-OF-THE-ART
- ASSIST IN EVALUATION OF IDEAS AND CONCEPTS WHICH COULD IMPROVE OTEC PERFORMANCE OR REDUCE COST
- DEVELOP DATA BASE ON WHICH TO EVALUATE OTEC PLANT COMPONENTS, SUBSYSTEMS, AND SYSTEMS

TEST REQUIREMENTS

A comprehensive test program has been envisioned by ERDA in accomplishing the OTEC program objectives of developing an industrial and technological base that will lead to the commercial capability to successfully construct and economically operate commercial OTEC plants. The test program provides the mechanism for focusing on and monitoring the hardware and procedural developments required for meeting the objective, whether it be by adaptation of existing hardware or by advanced research and development programs. Further, ERDA has planned that both land-based and at-sea test facilities will be utilized.

A-13 To derive the test facility requirements, the requirements for the test program must be established. The basis for the test requirements is the Statement of Work for the OTEC Test Facility Study Program. These test requirements, summarized in the chart, start with systems, cycle plant, or OTEC plant tests, demonstrations or exercises which are necessary to define and evaluate the power cycle capability (and key power cycle ancillary equipment) on a scaled basis at design or slightly off the design point, with emphasis placed on power cycle requirements. Secondly, alternative equipments or components, subsystems, and systems must also be tested in a logical and economical manner in order to define the concepts and configurations which best meet the OTEC plant objectives of performance, life costs, and operational requirements. The test requirements also include advancing OTEC component or procedural state-of-the-art through tests, experiments, and/or analyses. Thirdly, the test requirements include the capability of assisting (conducting experiments, monitoring tests, or analyzing results) in the evaluation of ideas and concepts which potentially could improve OTEC performance (higher energy output or supplanting in an economical manner land-based processes) or reduce cost (lower cost for energy). Lastly, the test requirements include the establishment of a data base on which to evaluate the myriad OTEC plant concepts, components, and system schemes, configurations, and procedures.

BASELINE REVISION

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

BASELINE REVISION

Baseline Configuration Changes

Baseline Power Cycle Changes

OTEC Plant Electric Power Output

Comparison of 25th Production Unit Cost

Cost of Energy Comparison

BASELINE CONFIGURATION CHANGES

DESIGN DATA COMPARISON

<u>ITEM</u>	<u>APRIL 1975</u>	<u>JUNE 1976</u>
COLD WATER PIPE LENGTH (FT)	1,000	2,000
COLD WATER INTAKE DEPTH (FT)	1,545	2,545
EVAPORATOR		
TUBE WALL THICKNESS (IN.)	0.028	0.034
TUBE ID (IN.)	1.944	1.932
TUBE LENGTH (FT)	52.5	48.2
NUMBER OF TUBES	120,000	110,588
TUBE SPACING/DIA RATIO	1.20	1.25
CONDENSER		
TUBE WALL THICKNESS (IN.)	0.028	0.029
TUBE ID (IN.)	1.944	1.942
TUBE LENGTH (FT)	52.5	52.5
NUMBER OF TUBES	120,000	110,588
TUBE SPACING/DIA RATIO	1.20	1.25

BASELINE CONFIGURATION CHANGES

Two principal design changes account for the increased performance of the June 1976 Baseline over the April 1975 Baseline. These are in the cold water pipe and in the evaporator and condenser. The cold water pipe length was increased from 1000 to 2000 ft, lowering the cold water inlet depth from 1545 ft to 2545 ft. The evaporator and condenser changes, based on discussions conducted with heat exchanger manufacturers and stress analyses of the tubes, are: an increased tube wall thickness; an increased tube spacing to diameter ratio, consequently with a reduction in the number of tubes as the shell diameter was held constant; and a change in the length of the evaporator tubes.

BASELINE POWER CYCLE CHANGES

MODULE/CYCLE COMPARISON

	APRIL 1975	JUNE 1976
WARM WATER INLET TEMP (°F)	79.75	79.75
COLD WATER INLET TEMP (°F)	46.50	41.76
INLET WATER TEMP DELTA (°F)	33.25	37.98
HEAT EXCHANGER LMTD (°F)		
EVAPORATOR	4.50	7.56
CONDENSER	4.42	7.68
TOTAL SEA WATER FLOW/MODULE (CFS)	28016	28175
RATIO WATER FLOW WARM/COLD	0.756	1.065
OVERALL HEAT TRANSFER COEF. (BTU/HR FT ² °F)		
EVAPORATOR	460 (493)	505 (540)
CONDENSER	434 (479)	441 (490)
FOULING RESISTANCE (HR FT ² °F/BTU)	0.0003	0.0001
TUBE SEA WATER VELOCITY (FPS)		
EVAPORATOR	5.00	6.46
CONDENSER	6.61	6.00
TOTAL HEAT FLOW ACROSS (BTU/SEC 10 ⁶)		
EVAPORATOR	1.774	2.858
CONDENSER	1.714	2.774
GROSS TURBINE POWER, MW	63.9	91.8

BASELINE POWER CYCLE CHANGES

The performance changes from the April 1975 Baseline to the June 1976 Baseline are tabulated in this chart. The principal change, that which provided the significant increased plant output, is the lower cold water inlet temperature by about 4.7° F yielding an increased inlet water temperature differential (warm-cold) of about 14%. This effect is magnified in the evaporator and condenser into a 70% increase in LMTD.

Another Baseline change is the total water flow and the ratio of warm water flow to cold water flow. These changes provide for higher sea water velocities and an increase in the overall heat transfer coefficients. It should be noted that a fouling resistance factor of 0.0001 was used in the June 1976 Baseline. However, a review of single-phase convective heat transfer correlation in the literature has revealed that the long-used Dittus and Boeltier equation is apparently 20% conservative (low) for the range of Prandtl and Reynolds numbers typical of the cold sea water passages in the condenser and about 15% conservative (low) for the evaporator sea water passages. This results in an overall heat transfer (U) improvement of plus 11% for the condenser and plus 7% for evaporator. These numbers are given in the parentheses in the chart. They will be held as a contingency against unforeseen performance penalties which could develop as well as a hedge against the fouling resistance factor.

OTEC PLANT ELECTRIC POWER OUTPUT

FOUR MODULES

<u>ITEM</u>	<u>APRIL 1975 BASELINE (KW)</u>	<u>JUNE 1976 BASELINE (KW)</u>
GENERATOR GROSS OUTPUT	<u>249,800</u>	<u>361,552</u>
PLANT CYCLE AUXILIARIES	84,600	84,664
MODULE SUPPORT SYSTEMS	332	2,832
CORE SUPPORT SYSTEMS	314	854
LOSSES - INTERNAL TRANSMISSION	1,705	3,336
STEPUP TRANSFORMER INPUT	<u>162,349</u>	<u>269,866</u>
LOSSES - TRANSFORMER/RECTIFIER	3,065	5,397
PLANT ELECTRIC OUTPUT - NET	<u>159,784</u>	<u>264,469</u>

POWER OUTPUT

The Baseline OTEC plant was modified based on studies conducted during the spring of 1976 as part of Task 1. The June 1976 Baseline is presented compared to the Baseline published in LMSC's OTEC Power Plant Technical and Economic Feasibility report of April 1975. The June 1976 Baseline generator gross output was increased by 45% over the April 1975 Baseline, while the calculated parasitic power and losses increased approximately 8%. The plant net electric output therefore increased by 66%.

COMPARISON OF 25TH PRODUCTION UNIT COST

\$M

ITEM	APRIL 1975 BASELINE	JUNE 1976 BASELINE
MODULES - SHELLS	24.9	24.8
MODULES - HEAT EXCHANGERS	264.8	221.3
MODULES - ROTATING EQUIPMENT	43.0	49.7
MODULES - OTHER	22.4	34.8
PLATFORM - CORE	40.6	42.0
PLATFORM - OTHER	15.1	18.5
COLD WATER PIPE	7.4	12.3
MOORING SYSTEM	34.7	34.1
INTEGRATION AND CHECKOUT	5.6	5.6
FACILITY PREPARATION	5.9	7.2
TOTAL	464.4	450.3
NET OUTPUT	159.8	264.5
DOLLARS/KW	2906	1700

COMPARISON OF 25TH PRODUCTION UNIT COST

As was done in 1975, a 93% learning curve was applied to the cost of producing the plants. The 25th OTEC plant was arbitrarily selected for comparison. The equivalent of a 12% escalation factor was applied to the 1975 estimates to make them directly comparable to the 1976 estimates. Other significant changes include:

- (1) The heat exchanger (modules-heat exchangers) tube sheets were redesigned to reduce their thickness.
- (2) Rotating machinery and electrical equipment (lines 3, 4, and 6) were increased to accommodate the greater output.
- (3) The platform buoyancy tanks (platform-core) were increased to accommodate the additional weight of the cold water pipe.
- (4) The cold water pipe was extended by 1000 ft.
- (5) Facility preparation was increased to accommodate the longer cold water pipe.

COST OF ENERGY COMPARISON

	1975	1976
NET TOTAL POWER OUTPUT, MW	160	264
TOTAL CAPITAL INVESTMENT, \$M	464.4	450.3
CAPITAL INVESTMENT, \$/KW	2906	1700
AVAILABILITY FACTOR	0.9	0.9
FIXED ANNUAL CHARGE, %	0.15	0.15
CAPITAL CHARGE, MILLS/KWH	55.3	32.3
O&M, MILLS/KWH	1.8	1.1
TOTAL MILLS/KWH	57.1	33.4

COST OF ENERGY COMPARISON

The projected cost of busbar electricity for the 1976 Baseline is approximately one half of that projected for the 1975 Baseline. The decrease is attributable basically to the increase in busbar output. Although labor rates were increased by 12% for the O&M charges, the O&M rates were decreased to 1.1 by virtue of the increased plant output.

TEST PLANS

PRESENTED BY
MURRAY I. LEITNER

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TEST PLANS

Test Planning Rationale

Test Programs Progression

Test Activities

Engineering Development

Advanced Research and Technology

System Components

Cycle Plant

TEST PLANNING RATIONALE

- IDENTIFY TEST PHASES LEADING TO EVENTUAL DEVELOPMENT OF OTEC PRODUCTION PLANT
- DELINEATE COMPONENTS OR SUBSYSTEMS REQUIRING DEVELOPMENT TESTING
- DEFINE AREAS FOR PERFORMANCE IMPROVEMENTS THROUGH AR&T
- INDICATE GENERIC TYPE OF FACILITIES REQUIRED FOR EACH TEST PHASE
- IDENTIFY AND PREPARE TYPICAL TEST PLANS

TEST PLANNING RATIONALE

Since the final objective of the testing program is the development of the OTEC production plant, the program should incorporate a logical progression of test phases which provide the confidence required to proceed to the objective.

The test program should therefore concentrate on those components or subsystems which are beyond the present "state-of-practice" from physical or operational standpoints and which require development testing to assure that the performance of these components or subsystems is compatible with the requirements of the OTEC production plant.

In addition, the testing program should also include those areas in which advances in systems performance or reductions in cost can be made through advanced research and technology.

The planning associated with this test program includes the type of test, suggested hardware sizes, and generic types of facilities in which these tests can be accomplished.

TEST PROGRAMS PROGRESSION

TEST PROGRAM PROGRESSION

A logical progression of tests leading to the design, development, construction, and operation of an OTEC demonstration plant and, ultimately, OTEC production plants, is shown. While Advanced Research and Technology is not required for the development of a baseline installation, new ideas and concepts will progress from AR&T through the various phases prior to application to the OTEC production plants.

The results of the test phases from AR&T through the Sea Eased Pilot Plant will serve as inputs to the OTEC system design and performance specification as they progress from preliminary through interim to final documentation. These final documents will define the design and specify the performance of the OTEC demonstration and production plants.

C-7 An additional test phase, entitled Engineering Development, is shown. Testing in this phase is done to ensure that the design is satisfactory, mainly from a fluid dynamic standpoint, and that changes made to reflect the results of AR&T do not introduce any unforeseen operational problems.

TEST PROGRAM PROGRESSION

This page was intentionally
left blank

TEST ACTIVITIES

ITEM	ENG DEV	AR & T	MAJOR COMP	LAND- BASED CYCLE	SEA- BASED CYCLE
WATER SIDE HEAT TRANSFER ENHANCEMENT					
INTERNAL VANE – STATIC OR ROTATING		A			
SPECIAL TUBE SURFACES		A			
WORKING FLUID DISTRIBUTION					
FLUID FEED CONFIGURATIONS		A	C		
SPECIAL TUBE SURFACES		A	C		
EFFECT OF SURFACTANTS		A	C		
HEAT EXCHANGER GEOMETRY					
TUBE ORIENTATION & SPACING		A/C	C		
SERPENTINE TUBE (APL)		A/C	C		
PANEL TYPE (METALLIC AND PLASTIC)		A/C	C		
HEAT EXCHANGER PRODUCIBILITY					
FABRICATION TECHNIQUES		B	~		
ASSEMBLY TECHNIQUES		B	B/C		
ROTATING MACHINERY					
AMMONIA TURBINE DEVELOPMENT		B	B		
AMMONIA PUMP DEVELOPMENT			B		
SEA WATER PUMP DEVELOPMENT			B		

- A. LAB TESTS AT UNIVERSITY RESEARCH INSTITUTE, GOVT, OR CONTRACTOR FACILITIES.
 B. TESTS AT VENDOR OR CONTRACTOR FACILITIES.
 C. TESTS AT GOVT FACILITY PROPOSED HEREIN.

TEST ACTIVITIES MATRIX.

A listing of the test activities associated with attaining the goal of a practical cycle plant is presented. The assignment of activities to the various test categories was used to develop the test program progression diagram.

Chronologically, Advanced Research and Technology testing and Engineering Development testing could be accomplished simultaneously, early in the program, using available testing facilities. As indicated, AR&T efforts will continue and could become part of the activities of the proposed test facility. Engineering Development testing is usually accomplished early in the design phase of a program to assure that the fundamental design is valid. In this program, this type of testing is primarily associated with the hydrodynamic aspects of the system.

Development of major components will be accomplished by selected vendors. As the components become available, they will be installed into the component test facility for determination of the performance under controlled conditions. These components will then be installed into the Cycle Generating Plant and the total system performance will be evaluated.

This Test Activities Matrix should not be considered as a total listing but as an indication of the number and types of tests required to attain the objective noted above.

TEST ACTIVITIES (CONTINUED)

ITEM	ENG DEV	AR&T	MAJOR COMP	LAND- BASED CYCLE	SEA- BASED CYCLE
<u>HYDRODYNAMIC INVESTIGATION</u>					
FLOW DISTRIBUTION AT PUMP INLETS & OUTLETS	A				
EXHAUST FLOW REINGESTION	A				
COLD WATER PIPE FLOW	A				
PLATFORM DYNAMICS (GENERIC TYPE)	A				
MOORING SYSTEM STUDIES	A				
<u>BIO-FOULING INVESTIGATION</u>					
BIO-FOULING POTENTIAL (1)		A			C
ANTI-FOULING SYSTEM PERFORMANCE			C	C	C
LONG TERM EFFECT ON HEAT EXCHANGERS		A/B		C	C
<u>ELECTRIC POWER TRANSMISSION</u>					
HIGH VOLTAGE D. C. TRANSMISSION				C	C
UNDERWATER CABLE/SEA WATER RETURN		B			C
<u>CYCLE COMPONENT PERFORMANCE</u>					
HEAT EXCHANGERS (BASIC AND ADVANCED) (2)			C	C	C
TURBINE			C		
TURBINE/GENERATOR (COMBINED)				C	C
AMMONIA PUMP(S)			C	C	C
SEA WATER PUMP(S)					C

- A. LABORATORY TESTS AT UNIVERSITY, RESEARCH INSTITUTE, GOVT, OR CONTRACTOR FACILITIES.
 B. TESTS AT VENDOR OR CONTRACTOR FACILITIES.
 C. TESTS AT GOVT FACILITY PROPOSED HEREIN.
 (1) DEPENDENT UPON PERFORMANCE DEGRADATION.
 (2) DEPENDENT UPON RESULTS OF HEAT EXCHANGER STUDIES.

TEST ACTIVITIES (CONCLUDED)

ITEM	ENG DEV	AR & T	MAJOR COMP	LAND- BASED CYCLE	SEA- BASED CYCLE
COLD WATER PIPE					
FABRICATION TECHNIQUES			B		
SEAL DEVELOPMENT			B		
DEPLOYMENT			B		
MODIFIED PIPE PERFORMANCE			B		C
MOORING SYSTEM					
PRELIMINARY DEPLOYMENT			B		
MODIFIED SYSTEM PERFORMANCE					C
CONTROL SYSTEM					
COMPONENT DEVELOPMENT			B		
SYSTEM PERFORMANCE				C	C
ENERGY UTILIZATION					
PRELIMINARY PROCESS EVALUATION	A	A			
UTILIZATION AT SITE				C	C

- A. LAB TESTS AT UNIVERSITY, RESEARCH INSTITUTE, GOVT, OR CONTRACTOR FACILITIES.
 B. TESTS AT VENDOR OR CONTRACTOR FACILITIES.
 C. TESTS OF GOVT FACILITY PROPOSED HEREIN.

ENGINEERING DEVELOPMENT

OBJECTIVES

- VERIFY FUNDAMENTAL OTEC PLANT AND COMPONENT ASSUMPTIONS
- IDENTIFY AND RESOLVE POTENTIAL PROBLEM AREAS

SEAWATER FLUID DYNAMICS

- FLOW DISTRIBUTION AT SEAWATER PUMP INLETS
- FLOW DISTRIBUTION AT HEAT EXCHANGER INLETS
- SEAWATER REINGESTION
- COLD WATER PIPE FLOW

SYSTEM DYNAMICS

- PLATFORM RESPONSE CHARACTERISTICS
- MOORING SYSTEM LOADS & INTERACTIONS
- COLD WATER PIPE DYNAMICS

PRODUCIBILITY

ENERGY UTILIZATION

ENGINEERING DEVELOPMENT

Evaluation of all testing involved in the attainment of the objectives of the present study indicated that some of the recommended tests do not fall within the objectives of the AR&T, components, or cycle plant test programs. Accordingly, an additional test category was established for those tests whose objectives are to verify the validity of the design, primarily from a fluid dynamics standpoint, or to identify potential problem areas which might be attributable to proposed heat exchanger producibility or energy utilization concepts.

The fluid dynamics testing can be accomplished on small scale models using available hydraulics or hydrodynamics test facilities. System dynamics testing can also be accomplished on small scale models using available hydrodynamics or towing basin test facilities.

The results of the sea water pump inlet flow distribution tests will be used to develop the screens for duplicating the inlet flow characteristics during the full scale pump tests. Tests to determine the flow distribution at the heat exchanger inlets will indicate whether or not a uniform profile exists and, if not, what modifications are required to assure uniform flow into the heat exchanger tubes.

Similarly, tests will be undertaken to assure that new heat exchanger producibility concepts or energy utilization schemes do not introduce any unforeseen problem areas.

ENGINEERING DEVELOPMENT

OBJECTIVES

VERIFY FUNDAMENTAL OTEC PLANT AND COMPONENT DESIGN ASSUMPTIONS
IDENTIFY AND RESOLVE POTENTIAL PROBLEM AREAS

FLOW DISTRIBUTION AT SEA WATER PUMP INLET

PROVIDE DATA FOR SEA WATER PUMP PERFORMANCE TESTING

QUADRANT MODEL FOR EVAPORATOR PUMPS SATISFACTORY

PLENUM MODEL FOR CONDENSER PUMPS

HYDRAULIC TEST FACILITY

FLOW DISTRIBUTION AT HEAT EXCHANGER INLET

ASSURE FLOW UNIFORMITY ACROSS HEAT EXCHANGER

REQUIRES MULTIPLE PUMP FLOWS

EXIT DIFFUSER FOR UPSTREAM PUMP LOCATION

INLET CONTRACTION FOR DOWNSTREAM PUMP LOCATION

- HYDRODYNAMICS LABORATORY
- HYDRAULIC TEST FACILITY

EXHAUST FLOW REINGESTION

EFFLUX REINGESTION DETRIMENTAL $1^{\circ}\text{F } \Delta T \approx 7\% \text{ POWER}$

REQUIRES SIMULTANEOUS SOURCE AND SINK EFFECTS

EFFECT OF CURRENT

- HYDRODYNAMICS LABORATORY
- HYDRAULIC TEST FACILITY

COLD WATER PIPE FLOW

DETERMINE PRESSURE DROP AND EXIT FLOW

REQUIRES JOINTS AND EXIT PLENUM SIMULATION

SMALL SCALE MODEL SATISFACTORY

- HYDRODYNAMICS LABORATORY
- HYDRAULIC TEST FACILITY

PLATFORM & MOORING SYSTEM DYNAMICS

DETERMINE RESPONSE TO OCEAN TRANSIENTS

DYNAMICALLY SCALED MODELS REQUIRED

- HYDRAULICS LABORATORY
- TOWING BASIN
- CONTRACTOR FACILITIES

ENERGY UTILIZATION

EVALUATE PRESENT DAY PROCESSES

SMALL SCALE SATISFACTORY FOR PROCESS EVALUATION

- VENDORS FACILITIES
- CONTRACTORS FACILITIES

This page was intentionally
left blank

ADVANCED RESEARCH & TECHNOLOGY

OBJECTIVES

- ADVANCE STATE-OF-THE-ART
- PROVIDE COST REDUCTIONS

- HEAT TRANSFER ENHANCEMENT
- WORKING FLUID DYNAMICS
- HEAT EXCHANGER GEOMETRY
- HEAT EXCHANGER PRODUCIBILITY
- AMMONIA TURBINE DEVELOPMENT
- FOULING & CORROSION
- ENERGY UTILIZATION

ADVANCED RESEARCH AND TECHNOLOGY

Applied research in such areas as heat transfer, fluid flow, rotating machinery, fouling, and energy utilization can result in significant improvements in operating and economic performance of the OTEC power plant. This figure presents an overview of the various types of experimental efforts considered applicable to the AR&T portion of the program. As anticipated, the criticality of the heat exchangers makes them the prime candidates for the major portion of the AR&T effort.

Sea-water side heat transfer enhancement, working fluid dynamics, and the effect of heat exchanger geometry (tube orientation and spacing) can be investigated with a single tube or a small array of tubes in a laboratory environment. Heat exchanger producibility studies, aimed at improving fabrication techniques and reducing fabrication costs, can be accomplished on small heat exchanger segments.

Ammonia turbine development can be initially undertaken with small-scale turbines at vendors facilities, which may require modifications for the ammonia utilization. Parametric performance data as a function of ammonia quality as well as comparative performance with air as the working medium will be obtained.

Fouling and corrosion potential should be investigated for both the sea water and working fluid sides of the heat exchangers. These studies can be accomplished on a single tube or small array, but must be done in the appropriate environment with the sea water velocity and temperature or ammonia flow rate and temperature varied as required.

Evaluation of new, advanced energy utilization schemes can be accomplished with small scale duplication of proposed processes. Advanced methods for power transmission can be evaluated using small sections of the full scale article, but requires that testing be done in the appropriate (sea-water) environment.

ADVANCED RESEARCH & TECHNOLOGY

OBJECTIVES

- ADVANCE "STATE-OF-THE-ART" IN CRITICAL PERFORMANCE AREAS
- ADVANCE "STATE-OF-THE-INDUSTRY" IN CRITICAL FABRICATION AREAS
- PROVIDE REDUCTIONS IN PRODUCTION, OPERATING, OR ENERGY UTILIZATION COSTS

HEAT TRANSFER ENHANCEMENT

IMPROVE WATER SIDE HEAT TRANSFER

- INTERNAL VANE
- SPECIAL TUBE SURFACES

SINGLE TUBE SATISFACTORY

- RESEARCH LABORATORIES
- UNIVERSITIES
- CONTRACTORS FACILITIES

WORKING FLUID DISTRIBUTION

MAXIMIZE AMMONIA SIDE TUBE WETTING

- FLUID FEED CONFIG.
- SPECIAL TUBE SURFACES
- ADDITIVES

SMALL ARRAY OF TUBES REQUIRED

- RESEARCH LABORATORIES
- UNIVERSITIES
- CONTRACTORS FACILITIES

HEAT EXCHANGER GEOMETRY

MAXIMIZE INTERNAL PERFORMANCE

- TUBE SPACING & ORIENTATION
- SERPENTINE TUBE
- PANEL TYPE

SMALL ARRAY OF TUBES REQUIRED

- RESEARCH LABORATORIES
- UNIVERSITIES
- CONTRACTORS FACILITIES

HEAT EXCHANGER PRODUCTIBILITY

IMPROVE FABRICATION TECHNIQUES

- MATERIALS
- ASSEMBLY TECHNIQUES

EXCHANGER SEGMENTS REQUIRED

- MANUFACTURERS FACILITIES
- CONTRACTORS FACILITIES

AMMONIA TURBINE DEVELOPMENT

DETERMINE PARAMETRIC PERFORMANCE

SMALL-SCALE TURBINE SATISFACTORY

VENDOR FACILITIES
MAY REQUIRE MODIFICATION FOR AMMONIA

BIO-FOULING INVESTIGATION

DETERMINE BIO-FOULING POTENTIAL

SINGLE TUBE SATISFACTORY

REQUIRES IN-SITU ENVIRONMENT

- MARINE LABORATORIES
- OCEANOGRAPHIC INSTITUTES
- UNIVERSITIES

ENERGY UTILIZATION

EVALUATE PROPOSED SCHEMES

- UNDERWATER TRANSMISSION
- ON-SITE UTILIZATION

IN-SITU ENVIRONMENT FOR POWER TRANSMISSION

SMALL-SCALE SATISFACTORY FOR PROCESS EVALUATION

- VENDORS FACILITIES
- CONTRACTORS FACILITIES

This page was intentionally
left blank

SYSTEM COMPONENTS

OBJECTIVES

- DETERMINE COMPONENT PERFORMANCE UNDER CONTROLLED CONDITIONS
- PROVIDE CONFIDENCE TO PROCEED WITH CYCLE PLANT

- HEAT EXCHANGERS
- ROTATING MACHINERY
- CONTROL SYSTEM
- ANTI-FOULING SYSTEM
- AMMONIA CLEAN-UP SYSTEM

SYSTEM COMPONENTS

The physical sizes of the OTEC plant major components are such that performance computations based on available data may not be accurate. It is, therefore, necessary to conduct tests on these components utilizing the full-scale hardware where feasible and, where infeasible, assuring that the test hardware size is large enough to provide the confidence necessary to proceed with the next phase of the test program progression.

Present planning includes testing of the sea water pumps, the control system, and the ammonia clean-up system utilizing full-scale hardware. Ammonia turbine testing will be conducted on sub-scale and full-scale hardware while the heat exchangers and the related anti-fouling system will be tested with sub-scale hardware.

SYSTEM COMPONENTS

This page was intentionally
left blank

CYCLE PLANT

OBJECTIVES

- CONFIRM VALIDITY OF CYCLE ASSUMPTIONS
- DETERMINE COMPONENT INTERACTIONS
- PROVIDE CONFIDENCE TO PROCEED TO FULL SCALE POWER MODULE

THERMODYNAMIC PERFORMANCE

- HEAT EXCHANGERS
- AMMONIA TURBINE
- AMMONIA PUMPS

OPERATIONS

- CONTROL SYSTEM
- ANTI-FOULING SYSTEM
- AMMONIA CLEAN-UP SYSTEM
- MAINTENANCE
- ENERGY UTILIZATION

CYCLE PLANT

The Cycle Plant, which is a major milestone in the OTEC program, presents the first opportunity to evaluate the complete thermodynamic performance and obtain operational data. The objectives of Cycle Plant operation are: (1) to confirm the validity of the assumption made in the prediction of the thermodynamic performance, (2) to determine the existence of component interactions, and (3) to provide the confidence to proceed with the construction of a full scale module for the sea based Pilot Plant.

Instrumentation will be provided to obtain pressures, temperatures, flow rates, and qualities as necessary to compute the thermodynamic performance. The ammonia power turbine will be instrumented to obtain the power output and the pump motors instrumented to obtain input power requirements.

Operational data will include the control system performance during startup and shutdown, its response to system transients and hazard signals, and its ability to control the output. The anti-fouling system will be utilized as warranted by heat exchanger performance degradation. Performance of the ammonia clean-up system will be obtained by injecting known quantities of water into the ammonia and sampling the flow at points within the system. Maintenance data will be accumulated through a regular inspection process. If warranted by cycle plant self-sufficiency, the feasibility and economics of proposed energy utilization schemes can be evaluated.

CYCLE PLANT

OTEC ENERGY UTILIZATION MODES

PRESENTED BY
WILLIAM H. CUTLER

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ENERGY UTILIZATION MODES

Study approach

Electrical transmission

Cost of electricity

Preline transmission

Delivered cost for liquid ammonia

Delivered cost for gaseous hydrogen

Barge transmission

Ammonia tug/barge operating costs

Barge shipping cost for ammonia

Comparison with existing LNG shipping

Barge shipping cost for hydrogen

Market analysis

Market regions

Projected demand for electricity, ammonia,
and hydrogen in southeast U. S.

Market potential

Platform configuration

Hydrogen properties affecting safety

Hydrogen production process

Hydrogen plant layout

Hydrogen plant costs

Ammonia production process

Ammonia plant layout

Ammonia plant costs

Platform integration

Energy transmission modes

Hardware development priorities

Electrical development areas

Swivel requirements

Swivel

Swivel installation and retrieval

Testing requirements

STUDY APPROACH

- ENERGY TRANSMISSION COSTS
- PLATFORM-BORNE SYSTEMS
- TESTING REQUIREMENTS

STUDY APPROACH

OTEC energy is transmitted by submarine cable to land-based electrical distribution systems, or used in production of profitable chemicals or industrial products on-board the OTEC platform. Each energy utilization mode will require testing in development of new components and verification of performance and reliability under unique OTEC operating conditions. The impact of such testing on the test facility plan is determined by (1) technical evaluation of each mode, (2) economic analysis, and (3) enumeration of test requirements. In this study, the modes considered are electrical transmission and production of hydrogen or ammonia.

Energy transmission costs are based on representative hardware designs for each mode, carried out in adequate detail so that all major cost items are identified and accurately estimated. Designs and layouts are produced for platform-borne systems to verify feasibility and identify areas requiring additional design and development. The result is identification of areas where testing unique to the OTEC application is called for, and derivation of typical testing requirements for the test facility plan. Testing will be required in two general areas:

1. Performance improvement to make the OTEC system more economical.
2. Verification that equipment items have been satisfactorily adopted to the OTEC environment.

ELECTRICAL TRANSMISSION

BASIS FOR ANALYSIS

	125 KV	250 KV
TERMINAL COST_____	\$105 / KW	\$130 / KW
CABLE COST _____	\$20 / FT	\$35 / FT
CABLE LOSS _____ (1000 KCM)	0.1266 MWe / NM	0.0317 MWe / NM

TERMINAL LOSS_____ 4%

CABLE LAYING COST _____ \$15,000. / NM

SWIVEL COST _____ \$300,000

MAINTENANCE (TERMINALS) _____ \$215 / MW-YR 0.0245 MIL / KWH

FIXED CHARGE _____ 15%

ELECTRICAL TRANSMISSION

Since the OTEC plant inherently generates electricity, which is the highest quality energy form in wide commercial use, it is most desirable to deliver OTEC energy to the user in that form. This requires a cable system to transmit the power from the OTEC plant to a shore terminal. For conventional submarine cables longer than 30 mi, AC transmission becomes uneconomical, and beyond 50 mi impossible, because of losses from circulating reactive currents. High voltage DC (HVDC) systems provide the practical alternative. A representative HVDC system has been configured for a 240 MW_e OTEC plant with single point mooring, as a basis for analysis of costs.

It consists of the following main components:

- AC-DC conversion terminal on board the OTEC platform
- Riser cables from sea floor to platform along the mooring line
- Cable swivel at the anchor pivot axis
- Sea floor cables from anchor to shore
- DC-AC conversion terminal on shore

A two pole, two cable system operating at ± 125 KV and 1000 amp is the baseline for cost calculations.

Rough cost figures are also provided for a 250 KV system as point of comparison. Capital cost, losses, and maintenance cost for AC-DC conversion terminals were provided by the General Electric Company. Simplex Wire and Cable Company and ITT/STK provided cable capital and laying costs. Swivel cost and fixed charge rates are LMSC estimates. Cable loss is calculated using a conductor cross section of 1000 KCM (kilo circular mil) at 70° F.

COST OF ELECTRICITY

COST OF ELECTRICITY

The cost of electricity delivered by the 125 KV and 250 KV systems is plotted as a function of the rate charged at the OTEC generator output terminal, with transmission distance as parameter. Costs were figured for systems having one, two, and three parallel cables per pole, and the system providing the minimum rate for delivered power was chosen. In three cases (indicated by *), in which the 125 KV system is transmitting power over distances of 500 NM to 1000 NM, a four cable system (two parallel cables per pole) proved most economical. In all other cases a single cable per pole is used.

The 250 KV system, in spite of its greater cost, is more economical for the longer distances and the higher cost OTEC electricity because it has lower losses and delivers a greater percentage of the generated power.

D-9

If high transmission efficiency, in order to maximize utilization of the ocean thermal resource, is included as an optimization criterion, then systems with multiple cables per pole or higher transmission voltages will be favored. For example, at a transmission distance of 300 mi, changing from a single cable to two cables per pole increases the delivered rate by 1 MILL/KWH while increasing the capacity delivered at landfall by 11% and also increases reliability.

These preliminary results demonstrate the potential for economic feasibility of long range electrical power transmission from OTEC plants, and indicate the direction of trends of cost versus technical parameters. Further optimization would be based on parametric models of the cost of cables and conversion equipment as a function of voltage, current, and reliability, coupled with more detailed information on the thermal resource at a selected site and the sea floor profile from site to landfall.

PIPELINE TRANSMISSION

INSTALLED COST
PUMPING COST

VS
VS

DIAMETER & DISTANCE
DIAMETER & DISTANCE

PIPELINE TRANSMISSION

The analysis of pipeline transmission begins with an optimization to determine the pipeline size by trading off the capital cost of the pipeline against the operating costs of pumping the product. The optimization is based on cost of installed pipe as a function of diameter, pumping power at 25 MILL/KWH, and a fixed charge rate of 10% (no maintenance or insurance included). At any given pipeline distance, the total lifetime cost of the system (plotted in arbitrary relative units, not dollars) as a function of pipe size shows a minimum, because a small diameter, inexpensive pipe will have high pumping loss while a large, low-loss pipe will be costly to install.

With hydrogen the longer pipeline distances result in a smaller diameter for the optimum pipe because hydrogen is compressible, having a lower specific volume at the higher pressure required to feed the longer pipe. This suggests that a tapered pipeline, small at the OTEC plant and increasing in diameter toward landfall, would provide improved performance. However, to avoid excessive complication, and because the optima are rather broad, a six-inch diameter was chosen as a near-optimum compromise for all pipeline distances.

With ammonia, the minimum cost occurs with four-inch pipe for all distances.

DELIVERED COST FOR LIQUID AMMONIA

DELIVERED COST FOR LIQUID AMMONIA

Having chosen the 4-in. pipeline as optimum for ammonia, the cost of the product is plotted as a function of the capital charge rate, with pipeline transport distance as parameter. The cost of the product is based on the total capital investment in the plant and pipeline. The cost of pumping is now included in terms of that portion of the OTEC plant capacity (and hence that portion of capital cost) which is required to run the pumps. The busbar rate for electricity at the OTEC plant does not appear as a parameter since generation of electricity is only one step in the process of producing ammonia from ocean thermal energy, the other steps being production of hydrogen by electrolysis of desalinated seawater, production of nitrogen from air, ammonia synthesis, and pumping the product.

The assumed capital costs include the baseline OTEC plant, modification of the plant to add the pipeline riser and space for the ammonia production equipment, and the cost of the ammonia production equipment itself. The ammonia manufacturing capacity of 810 ton/day is based on an OTEC plant busbar capacity of 270 MW_e.

DELIVERED COST FOR GASEOUS HYDROGEN

D-14

DELIVERED COST FOR GASEOUS HYDROGEN

Having chosen the 6-in. pipeline as optimum for hydrogen, the cost of the product is plotted as a function of the capital charge rate, with pipeline transport distance as parameter. The cost of the product is based on the total capital investment in the plant and pipeline. The cost of pumping is now included in terms of that portion of the OTEC plant capacity (and hence that portion of capital cost) which is required to run the pumps. The busbar rate for electricity at the OTEC plant does not appear as a parameter since generation of electricity is only one step in the process of producing hydrogen from ocean thermal energy, the other steps being electrolysis of desalinated seawater, and pumping the product.

The assumed capital costs include the baseline OTEC plant, modification of the plant to add the pipeline riser and space for the hydrogen production equipment, and the cost of the hydrogen production equipment itself. The hydrogen manufacturing capacity of 159 ton/day is based on an OTEC plant busbar capacity of 270 MW_e.

BARGE TRANSMISSION

BASIS FOR ANALYSIS

- EQUIPMENT COST
- OPERATING COST

BARGE TRANSMISSION

The economic analysis of barge transmission of ammonia and liquid hydrogen is based on a specific barge design which allows accurate estimates of equipment and operating costs. A notch-barge concept is used because it allows the barge to be moored to the OTEC plant and serve as the onsite storage while the tugs remain fully occupied with transporting product. The notch-barge with tug firmly mated in its stern notch is a proven seaworthy vessel with several advantages over a ship of similar capacity. It requires a smaller operating crew, the tug is under way a greater percentage of the time since delays for loading and unloading are avoided, maintenance can be carried out on tug or barge separately, transport system capacity can be expanded easily by adding tugs or barges as needed, the favorable financing rates which apply to shipping make the barge more economical for product storage at the OTEC plant site than tanks on board the platform, and it is safer to store product on the barge than on the platform.

The barges are designed around a modular storage tank of the largest size which can be handled by shipyard cranes. Barges are designed in two size ranges. The smaller range has tanks two abreast with a single tank in the bow as shown, and can accommodate 3, 5, or 7 tanks before the length-to-beam ratio becomes excessive. The larger size range has tanks three abreast, with a single tank and a pair in tandem in the bow. This type of barge can accommodate 15, 18 and for ammonia only, 21 tanks.

Ammonia is shipped under pressure to remain liquid at ambient temperatures, while hydrogen is shipped as liquid in double walled vacuum insulated cryogenic tanks.

AMMONIA TUG/BARGE OPERATING COSTS

AMMONIA TUG/BARGE OPERATING COSTS

For each size tug and barge, the capital cost and number of crew are determined. Daily operating costs are then calculated including crew wages, fuel, lubrication, and maintenance costs, finance and insurance charges. Costs for each size vessel are plotted as a function of the speed of the vessel, higher speed causing higher cost through increased tug power requirement and higher fuel consumption. Daily operating cost for the barge alone, operating as a storage vessel at the OTEC plant site, is also shown.

BARGE SHIPPING COST FOR AMMONIA

INCREMENTAL PRODUCT COST
VS
DISTANCE SHIPPED

SHIPPING COST
VS
DISTANCE SHIPPED

BARGE SHIPPING COST FOR AMMONIA

Calculation of barge shipping costs for ammonia requires definition of a scenario for barge operations. It is assumed that a single OTEC plant is being serviced, with product delivered to a single port, and a single type of tug/barge makes up the fleet. One barge is moored to the platform at all times to receive product while one or more tug/barges are in transit. Selection of the optimum type and number of vessels, and the speed for any given shipping distance was accomplished by making a matrix of combinations of barge type, number of tug/barges in the fleet, and operating speed (quantized to 10, 12.5, and 15 knots). The maximum range at which the OTEC plant production can be accommodated, incremental product cost in dollars per ton, and the shipping cost in dollars per ton-nm are calculated for each combination in the matrix. For any given distance shipped, the optimum combination of barge type, number of vessels, and speed is that which has range in excess of the distance shipped and results in the lowest incremental product cost. The resultant incremental product cost and shipping cost are plotted as functions of distance shipped.

The incremental product cost is reasonable compared to the current selling price of \$180 to \$200 per ton for ammonia. If future market conditions warrant introduction of OTEC produced ammonia, then barge shipping is a feasible and economical means of transport. For comparison, the equivalent incremental product cost as a function of distance shipped is also plotted for pipelined ammonia (numbers taken from "Delivered Cost for Liquid Ammonia" using 15% capital recovery rate). The comparison shows that pipeline shipment is superior to barges only for distances less than about 150 nm. At those distances power would probably be transmitted as electricity, so ammonia pipelines are not economically attractive in any situation.

COMPARISON WITH EXISTING LNG SHIPPING

COMPARISON WITH EXISTING LNG SHIPPING

Liquid hydrogen tug/barge vessels are similar in design to the ammonia vessels, except that double walled vacuum insulated cryogenic tanks are used. As point of reference the cost of the hydrogen barges is compared with the cost of vessels for transporting LNG, represented by results of a parametric study ("Perspective Economiques du Transport Maritime de Gaz Naturel Liquifie," Second International Conference on LNG, Paris, 1970) and two existing ships of the same capacity and cost (Maritime Reporter/Engineering News, 15 June, 1973, p. 8 and 15 Feb., 1976, p. 10). The hydrogen barge costs are somewhat higher than the extrapolation of LNG ship costs would lead one to expect. This may be due to sacrificing economy of scale with the smaller barges which have modular rather than built-in tanks as ships commonly have, and the more expensive construction and materials required for hydrogen because it is colder than LNG.

BARGE SHIPPING COST FOR HYDROGEN

BARGE SHIPPING COST FOR HYDROGEN

Incremental product cost and shipping cost for hydrogen are calculated using the methodology previously described for ammonia, and plotted together with equivalent costs for pipelined hydrogen. The graph indicates that for shipping distances greater than 200 to 300 nm, barge transportation is superior to hydrogen. However, the graph does not include the cost of liquifying hydrogen for barge shipment, which adds \$2 or \$3 per million BTU to the cost of barged hydrogen. Including this factor, the costs favor pipelined hydrogen to distances of about 1000 nm.

MARKET ANALYSIS

- SOUTHEAST U. S.
- ELECTRICITY, HYDROGEN, AMMONIA
- CAPITAL REQUIREMENTS
- HISTORICAL MARKET DATA

MARKET ANALYSIS

A market analysis was performed for the Southeast United States, the region most likely to receive initial benefit from OTEC implementation. The analysis covers the utilization modes of electricity, hydrogen, and ammonia. The result is projected demand to the year 2000 based on historical market data, and estimation of the capital required to fulfill the electrical demand. Further details of the method and results of analysis are given in Appendix 4, Section 4.8.

MARKET REGIONS

The market analysis includes the states of North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Arkansas, Louisiana, Texas, Oklahoma, and Kansas, with the states divided into Southeast region, South-central region, and Texas.

PROJECTED DEMAND FOR ELECTRICITY, AMMONIA, AND HYDROGEN IN SOUTHEAST U.S.

PROJECTED DEMAND FOR ELECTRICITY, AMMONIA AND HYDROGEN IN THE SOUTHEAST U. S.

In the time interval from present to 2000, electrical demand in Southeast U.S. is expected to grow at 6% to 8% average annual rate, as compared with about 3% nationwide. The demand for coal will grow accordingly as will the demand for nuclear power. Both of these energy sources are subject to serious social and economic limitations on their growth rates. In particular, meeting coal needs will require opening mines, adding rail capacity, and enlarging the labor force at a prodigious rate.

More than half of the ammonia consumption in Southeast U.S. goes into fertilizer, with a growing proportion being used for explosives, fibers, non-protein nitrogen in cattle feed, and other industrial uses. Ammonia is now made from natural gas, or, next in preference, from coal, both of which provide hydrogen and nitrogen by combustion with air and subsequent reaction with water. In terms of quantity, fossil fuel feedstocks will remain in adequate supply for ammonia demand, which does not increase rapidly in the next 24 years. However, policy decisions on allocation of fossil fuel resources may limit the supply feedstocks for ammonia.

Hydrogen is currently used in ammonia production, petroleum, and chemicals. Each of these industries has adequate captive supply at a cost well below that of hydrogen purchased from any outside source. The "most likely" hydrogen demand projection is an extension of these uses. However, in the next 24 years, new hydrogen uses for direct reduction of iron ore and production of synthetic fuels, if introduced widely, could push hydrogen demand to the level indicated by the "potential" curve. Nevertheless, hydrogen for these purposes is still most economically supplied from the reaction of fossil fuels, air, and water.

MARKET POTENTIAL

ELECTRICITY – HIGH POTENTIAL

- FASTEST GROWING MARKET AREA
- LOGISTICS BARRIERS TO OTHER SOURCES

AMMONIA – MODERATE POTENTIAL

- AGRICULTURE IS LARGEST MARKET
- OTEC AMMONIA RELIEVES DEMAND ON FOSSIL FEEDSTOCKS

HYDROGEN – LOW POTENTIAL

- CAPTIVE SOURCES ADEQUATE
- MAJOR DEMAND AWAITS HYDROGEN ECONOMY

MARKET POTENTIAL

The market analysis indicates a high potential for OTEC electricity, a moderate potential for ammonia depending on whether fossil feedstocks for ammonia are curtailed, and a potential for hydrogen only if the hydrogen economy becomes a reality.

The Southeast U. S. is the fastest growing market for electricity. Coal and nuclear power will be hard pressed to expand productive capacity to meet the demand, and public concern about environmental impact will add further restraint. In this market, OTEC-generated electricity can contribute significantly, at realistically achievable prices for the delivered power.

OTEC ammonia is nearly competitive at current prices (within a factor of 1-1/2 to 2). If the decision were made to curtail use of fossil feedstocks for ammonia production to save them for other more critical use, then OTEC ammonia would be the alternative. A distribution network would be required to move the product from ports of entry to the agricultural areas where the demand is greatest.

In the Southeast U. S. the demand for hydrogen is expected to be met by captive sources. Only if the hydrogen economy is introduced, in which hydrogen becomes a major fuel, would OTEC hydrogen find demand at any realistic price.

This page was intentionally
left blank

PLATFORM CONFIGURATION

Production of hydrogen or ammonia on board the OTEC plant requires integration of the production facility with the platform. As a part of the energy utilization task, a plant layout and estimate of the cost of the installed plant, exclusive of changes to the platform, was prepared.

In order to be conservative, the layout and cost estimate is based on current industrial practice. This is typified by the Lurgi electrolyzers used for hydrogen production, which are bulky in comparison with equipment now under development by Teledyne and General Electric. As a result, considerable volume is added to the platform to house the equipment. For reasons of safety and economics, the volume was added above the waterline at the top of the highrise structure, as shown.

The added space and equipment adds weight, requiring some increase in the volume of buoyancy tanks. However, it also adds reserve buoyancy, providing an additional margin of safety. The overhanging decks are 80 ft above nominal waterline and therefore out of reach of heavy wave loadings. The wind forces on the added exposed surface are within the platform stability and mooring strength limits. All hydrogen and ammonia production equipment is above waterline and at the top of the platform where ventilation is readily provided, leaked hydrogen will move up and away from enclosed areas, and explosion damage will afford minimum risk to the platform. The side walls of the equipment space are blowout panels to relieve pressure in event of an explosion.

The top deck serves as a helicopter landing area and is equipped with a crane for handling equipment.

Since the electrolysis equipment can be powered directly by DC generators in the OTEC power modules, much of the electrical equipment which was to be housed in the platform core can be eliminated. This space is used for the desalination units which provide pure water to the electrolyzers.

HYDROGEN PROPERTIES AFFECTING SAFETY

1. IT IS COLORLESS AND ODORLESS.
2. SPECIFIC GRAVITY RELATIVE TO AIR: 0.069
3. AUTOIGNITION TEMPERATURE IN AIR: 1065°F
4. FLAMMABILITY LIMITS IN AIR: 4.0 TO 75 VOL %
5. DETONATION LIMITS IN AIR: 18.3 TO 59 VOL %
6. MINIMUM SPARK IGNITION ENERGY IN AIR: 0.00002 JOULE
(ABOUT 1/10 THAT OF GASOLINE IN AIR)
7. THE FLAME IS COLORLESS.
8. HYDROGEN DIFFUSES 4 TIMES FASTER THAN AIR.
9. HYDROGEN WILL LEAK TWICE AS FAST AS AIR THROUGH
A GIVEN HOLE.
10. ELECTRICAL EQUIPMENT FOR HYDROGEN AREAS MUST
BE CLASS 1, GROUP B, DIVISION 2.

(INFORMATION FROM "HYDROGEN SAFETY MANUAL", NASA, 1968)

HYDROGEN PROPERTIES AFFECTING SAFETY

The properties of hydrogen make it particularly hazardous with regard to fire and explosion. It can be handled safely by providing adequate ventilation, eliminating ignition sources, and installing a detection and warning system. These requirements together with a layout which minimizes damage in event of an accident are determining factors in design of the OTEC hydrogen electrolysis plant.

HYDROGEN PRODUCTION PROCESS

HYDROGEN PRODUCTION PROCESS

Desalinated seawater is electrolyzed into hydrogen and oxygen. The oxygen, being of too little value to be shipped, is vented. The hydrogen is compressed for pipelining or liquified for barge transport.

The layout is based on Israeli Desalination Engineering vapor compression desalination units, Lurgi Electrolyzers, and the necessary auxiliary equipment. Three desalination units of 500 ton per day capacity are used. These together with the 1000 ton storage provide enough capacity for the 1260 ton per day requirement of the OTEC plant (including cooling makeup and crew supplies) with reserve to allow downtime for maintenance. Water for hydrogen production goes through a filter and ion exchange demineralizer.

The electrolyzers are built up of alternating anodes and cathodes held in a filter press frame. The electrolyte is potassium hydroxide. The electrolyzer modules operate at 1000 VDC.

This power is supplied directly by acyclic generators. Manufactured by General Electric, they have multiple copper disks on the single rotor shaft with liquid metal slip ring contacts around the full circumference of each disk. Their excitation field is normal to the disks and parallel to the shaft. They inherently have high current capacity and are well matched to the electrolyzers. Power is easily controlled by varying the excitation field. The electrolyzers can be connected directly to the generator bus with only a disconnect switch to separate the unit during maintenance periods. Separate AC generators are provided for auxiliary power.

Waste heat released within the electrolyzers is removed by circulating the electrolyte through heat exchangers. These are of material incompatible with seawater, so a secondary desalinated water cooling loop is required to finally dissipate this heat in a seawater heat exchanger. The electrolyzers produce gas at 410 psig. The vented oxygen is first expanded through a turbine generator, which recovers about 2 MW_e.

HYDROGEN PLANT LAYOUT

TYPICAL - LEVELS A, B, C, D

HYDROGEN PLANT LAYOUT

The hydrogen production plant is housed in the four levels at the top of the OTEC plant highrise, with typical layout as shown. Each level is powered independently by one of the power modules.

The electrolyzers are arranged radially in pairs. The longer radial objects at the top of the diagram are hydrogen and oxygen separation tanks. Electrolyte and nitrogen for purging hydrogen lines are stored in tanks indicated at the lower periphery. Pumps, filters, heat exchangers, and the like are located throughout the available space, in proximity to the units they serve.

HYDROGEN PLANT COSTS

	<u>\$1000's</u>
SEAWATER DESALINATION	1,300
ELECTROLYSIS MODULES	67,000
DC POWER DISTRIBUTION	1,100
HYDROGEN COMPRESSORS	2,100
OXYGEN EXPANDER AND GENERATOR	600
COOLING WATER SYSTEM	800
AUXILIARY SYSTEMS	500
INTERCONNECTING PIPING AND INSTRUMENTATION	3,200
ELECTRICAL SYSTEM	<u>3,500</u>
PROCESS PLANT FIELD COST	80,100
ALLOWANCE FOR UNCERTAINTY	<u>9,000</u>
ESTIMATED HYDROGEN PLANT COSTS	89,100

HYDROGEN PLANT COSTS

The cost of the hydrogen plant, installed and ready to operate, including all related equipment on the OTEC platform outside of the power modules, but excluding structural modifications to the platform, is estimated to be \$89,100,000.

AMMONIA PRODUCTION PROCESS

AMMONIA PRODUCTION PROCESS

Ammonia is produced on the OTEC plant by synthesis of electrolytic hydrogen with nitrogen from the atmosphere. A simplified schematic is shown. The three alternatives for producing the nitrogen feedstock are (1) combustion of hydrogen in air followed by drying of the combustion products, (2) liquification and distillation of air, and (3) combustion of ammonia in air to produce nitric acid and nitrogen. Combustion of hydrogen in air is ruled out immediately as uneconomical. The nitric acid process is potentially the most economical because the nitric acid is a high value product, but it complicates both the OTEC plant and the transportation link which delivers products to shore. Liquification and distillation was chosen as more straightforward, and also because the nitrogen feedstock produced is free of argon, carbon dioxide, and other trace impurities left in the feedstock by the nitric acid process, which would interfere with the ammonia synthesis.

D-45 The nitrogen is compressed, mixed in proper proportion with hydrogen, and passed through a Deoxo unit, a catalytic combustor which removes oxygen traces by converting them to water, and also protects the ammonia synthesizer from a burst of oxygen should the liquification plant malfunction. The mixed feedstock is then compressed for injection into the catalytic converter. Water is removed at this point by condensation in compressor interstage coolers. Since the synthesis of ammonia does not proceed to completion on a single pass through the converter, the product stream is recycled through the compressor. While shown as a single unit, the compressor actually consists of several stages, with product tapped off at various pressures to supply different functions within the synthesis loop and ammonia refrigerator.

The product is extracted from the process stream by the ammonia refrigerator, which uses part of the product ammonia as refrigerant to chill the process stream and condense out the ammonia fraction. The liquid ammonia is then pumped through a pipeline or loaded on barges for transportation to shore.

AMMONIA PLANT LAYOUT

AMMONIA PLANT LAYOUT

The layout of the ammonia plant equipment is as shown, the arrangement being typical of the four levels at the top of the OTEC platform. Most of the space is occupied by electrolysis equipment. The hydrogen and oxygen separators have been relocated to make room for the air liquification equipment, which is divided into three modules to allow routine maintenance on a rotating basis without hampering plant operation. The modules are housed in cold boxes indicated by three squares near the top of the diagram. The ammonia catalytic converter is indicated by the circle in the lower left quadrant of the diagram. The remainder of the equipment, compressors, pumps, filters, heat exchangers, and the like, is arranged in the available space.

The ammonia catalytic converter and air liquifaction plant extend vertically through all four levels of the ammonia plant. Special provision must be made in the structure for their installation.

AMMONIA PLANT COSTS

	<u>\$1000's</u>
● SEAWATER DESALINATION _____	1,300
● ELECTROLYSIS MODULES _____	67,000
● DC POWER DISTRIBUTION _____	1,100
● OXYGEN EXPANDER AND GENERATOR _____	600
● NITROGEN PLANT _____	9,800
● GAS COMPRESSION AND AMMONIA SYNTHESIS _____	14,700
● COOLING WATER SYSTEM _____	1,300
● AUXILIARY SYSTEMS _____	700
● INTERCONNECTING PIPING AND INSTRUMENTATION _____	5,300
● ELECTRICAL SYSTEM _____	<u>6,300</u>
PROCESS PLANT FIELD COST _____	108,100
● ALLOWANCE FOR UNCERTAINTY _____	<u>15,000</u>
● ESTIMATED AMMONIA PLANT COSTS _____	123,100

AMMONIA PLANT COSTS

The cost of the ammonia plant, installed and ready to operate, including all related equipment on the OTEC platform outside the power modules, but excluding structural modifications to the platform, is estimated to be \$123,100,000.

PLATFORM INTEGRATION

- STORAGE TANKS
- TALL EQUIPMENT
- INTEGRATED HEAT DISPOSAL
- RELIABILITY/EFFICIENCY/COST TRADEOFFS
- SAFETY

PLATFORM INTEGRATION

Storage tanks must be provided for purified water to feed the electrolyzers, and to accommodate product output flow whenever pipelines or barges are temporarily disconnected. Such tanks, being bulky and massive when loaded, are best accommodated within the core structure. This competes for space needed for other functions and requires structural modification of the basic platform.

Some of the process equipment items are tall, extending through several levels. The size of these items must be accommodated while preserving structural integrity and water tightness of compartments, and allowing access for installation and maintenance.

Waste heat from energy utilization processes can be recovered to improve plant efficiency. Waste heat can amount to about 10% of plant net output. Returned to the main power cycle, functioning at 3% efficiency, the waste heat can add 0.3% to net output, or about 0.8 MW_e. It is better to use waste heat for some auxiliary purpose such as preheating evaporator feed ammonia, or include a small secondary waste heat power cycle which can generate as much as 2 or 3 MW_e by operating at the higher temperatures at which waste heat is available.

Waste heat collection involves integration of the various heat sources through a multiplicity of fluid loops, with attendant complexity and materials compatibility problems involving fresh water, sea water, and other fluids.

The efficiency and reliability of energy utilization process equipment is a function output as a percentage of rated capacity. Derating can increase life and efficiency but also increases capital cost for a given plant capacity. Parametric studies are required to determine optimum operating points based on lifetime costs.

Safety of plant personnel and security of the plant have a major influence on the type of equipment chosen for energy utilization processes and the layout of the platform.

ENERGY TRANSMISSION MODES

CURRENT APPROACH

- ELECTRICAL CABLE
- PRODUCT (PIPE OR BARGE)

FUTURE CONCEPTS

- ENERGY CARRIER

ENERGY TRANSMISSION MODES

Conceptually, the current approach in the energy utilization study has been to consider modes which mesh with energy distribution and consumption systems now in place, and to project future changes in the magnitude of consumption within existing modes, but to consider no major change in types of modes which predominate, and to include no innovation. The result has been to limit the study to electrical cable transmission or production and transportation of a familiar bulk product, ammonia or hydrogen. This provides a sound conservative basis for economic feasibility demonstration.

However, it will be fruitful to expand the search for future concepts to include systems for which no current counterpart exists. One such system concept is the energy carrier, defined as material which circulates in a closed transportation loop, is activated at the OTEC plant, and releases its energy in usable form at a land-based terminal with high overall energy transport efficiency. An example of such a material is hydrogen chloride, which may be electrolyzed into hydrogen and chlorine at the OTEC plant and recombined on shore in suitable cells with high overall energy transfer efficiency. The identification and evaluation of energy carrier systems is a key element in the commercialization of OTEC.

HARDWARE DEVELOPMENT PRIORITIES

SYSTEM DEFINITION

- REPRESENTATIVE SITES
- COMPONENT COST AS FUNCTION OF CAPACITY AND PERFORMANCE
- FAILURE / CASUALTY RATE ESTIMATES
- OCEAN ENGINEERING EVALUATION OF MOORING / RISER ALTERNATIVES
- OPTIMIZATION CRITERIA

PRIORITY ASSIGNMENT

- IMPROVED CAPACITY OR PERFORMANCE
- INNOVATION

HARDWARE DEVELOPMENT PRIORITIES

Generalized site-independent energy utilization studies of conventional transmission modes have about reached the limit of their usefulness. System definition for several representative sites should be carried out to determine specific hardware requirements to provide a basis for assignment of priorities to further hardware development. System definition requires:

- (1) Component cost as a function of capacity and performance, and estimates of failure or casualty rates to allow tradeoffs over the life of the system including effects of efficiency, maintenance, and downtime.
- (2) Evaluation of mooring and riser alternatives, where applicable, against ocean engineering experience.
- (3) Definition of optimization criteria.

Having defined representative systems, it is then possible to assign priority to developments which will make such systems possible, either through improved capacity or performance, or through innovation to provide a key element which does not now exist.

ELECTRICAL DEVELOPMENT AREAS

- HIGHER VOLTAGE HARDWARE
- SEA FLOOR CABLE INTEGRITY
- ANCHOR CONNECTION
- CLUSTERING

ELECTRICAL DEVELOPMENT AREAS

Returning to conventional electrical transmission, the study has brought out areas in need of development. The economics favor higher transmission voltages. Cables and converter terminal equipment for higher voltage marine operation must be proven.

Cables must be developed for laying in deep open ocean and across uneven bottom contours. Equipment is needed for economically trenching cables deeply into the sea floor where hazard exists from trawler nets and dragging anchors.

Reliable equipment is needed for completing the cable connection between the anchor and floating platform.

Considering that several OTEC plants will probably be operated within any area to maximize utilization of the thermal resource, the impact on cable system design of clustering platforms around a central collection point must be studied.

SWIVEL REQUIREMENTS

- ALLOW SINGLE-POINT MOORING
- LONG, MAINTENANCE FREE LIFE (20 YR)
- RAPID INSTALLATION AND RETRIEVAL
- REPAIRABLE / REPLACEABLE ON SITE

SWIVEL REQUIREMENTS

Since LMSC has proposed a single-point mooring system, the feasibility of a swivel to carry electrical power through the anchor pivot point has received considerable attention. The entire power output of the OTEC plant passes through the swivel which is in a relatively inaccessible location on the ocean floor. To be economically acceptable, it must be designed, first, for high likelihood of long maintenance-free life. Then, in event repair is needed, the process of retrieval, repair or replacement, and re-installation must be rapidly accomplished to avoid excessive plant down time.

SWIVEL

SWIVEL

The swivel is designed to be installed concentric with the hollow, rotating anchor post. The shore cables emerge from the lower, non-rotating portion of the swivel below the bottom of the anchor post, and remain fixed in a slot in the anchor. The riser cables to the platform emerge from the upper portion of the swivel, which rotates with the anchor post. The swivel is filled with dielectric oil and hydrostatically balanced by a diaphragm which allows external seawater to pressurize the oil. The rotating joint in the swivel shell is sealed with redundant elastomer seals, and a void space drain between the seals diverts any leakage from reaching the interior of the swivel.

Cable slip rings are housed in ceramic retainers inside the top of the swivel. "Multilam", a multiple contact spring material, is inserted between contact surfaces to retain low contact resistance under slowly rotating conditions while immersed in oil. The shore and riser cables are plugged into the swivel through flanged seals to allow quick replacement. "Multilam" is also used in the plug connections, and for static connections inside the swivel as well.

SWIVEL INSTALLATION AND RETRIEVAL

D-62

SWIVEL INSTALLATION AND RETRIEVAL

If repair is needed, the steps are as follows:

1. The crane barge picks up the riser cable at the OTEC plant and reels in riser until arriving at the station directly over the swivel.
2. With help of a submersible, a lifting line from a crane barge is attached to a bail on top of the swivel, and strain relief rigging is attached to the shore cable.
3. If necessary, the OTEC platform is towed to position to index the anchor post slot to free the shore cable.
4. The swivel is raised while the crane barge reels in the riser cable, and the surface vessels move to maintain the proper catenary on the shore cables.
5. When on the surface, the swivel is repaired or replaced.
6. The process is reversed for installation.

TESTING REQUIREMENTS

ITEM	TEST OBJECTIVE	CATEGORY				
		ENG DEV	AR&T	COMP	CYCLE PLANT LAND	CYCLE PLANT SEA
ELECTRICAL TRANSMISSION (CABLE, SWIVEL, RISER, CONNECTOR, SEA WATER RETURN)	MECHANICAL, ELECTRICAL INTEGRITY	X	X			
	LAYING, INSTALLATION	X	X	X		X
AC-DC CONVERSION EQUIPMENT	MARINE ENVIRONMENT			X		
	SYSTEM INTERACTIONS				X (OR)	X
PIPELINE (RISER, SWIVEL, COUPLING)	MECHANICAL INTEGRITY		X			
PROCESS EQUIPMENT (ELECTROLYZER, REACTION VESSEL, PUMPS, FILTERS, HEAT EXCHANGERS)	PRELIMINARY PROCESS EVALUATION		X			
	MARINE ENVIRONMENT			X		
	SYSTEM INTERACTIONS				X (OR)	X
PRODUCT TRANSFER EQUIPMENT	MARINE ENVIRONMENT			X		X

TESTING REQUIREMENTS

High reliability of electrical transmission is mandatory because extended shutdown of the high capital OTEC plant is economically unacceptable, and repairs to transmission equipment may be lengthy. Cable dielectrics, sheathing, and armoring systems require improvement over existing practice. New developments are required to complete the circuit from sea floor cable to platform. Effects of large electrical currents in the ocean resulting from use of a seawater return circuit require investigation. Design verification testing will be required if the first OTEC at-sea demonstration is to transmit electrical power to land.

AC-DC conversion equipment is well understood for land-based applications and requires testing only to verify operation under unique OTEC conditions. Pipelines require development to extend practice to deeper water and provide the connection from sea floor to platform.

There are many candidate processes for non-electrical utilization of OTEC energy, in areas of both marketable products and the energy carrier concept. These will require testing, first, to evaluate technical and economic feasibility. Then, as part of the commercialization of selected processes, performance of components must be verified under OTEC operating conditions, and the interface compatibility between the process and OTEC power cycle must be demonstrated.

Operation of product transfer equipment for loading barges must be verified in the open seas and procedures developed for all weather conditions.

OTEC SCALING ANALYSIS

PRESENTED BY
WILLIAM L. OWENS

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

SCALING ANALYSIS

Requirements for flow similitude

OTEC power cycle component scaling technology

Turbine scaling

Pump scaling

Turbine and sea water pump diameter and speed as a function of net power

Methods of predicting full scale pump efficiency from model pump data

Evaporator design

Maximum evaporator mass rate as a function of shell diameter

Variation of NH_3 evaporator feed-line orifice diameter

Comparison of vertical and horizontal vaporization heat transfer coefficients

Overall heat transfer coefficient vs sea water velocity

Chen's expression for laminar film condensation on horizontal tubes

Relationship between mass flow rate and number of tubes for condensing ammonia at 50° F

Comparison of OTEC heat exchanger requirements with current technology

Critical vapor velocity for tube vibration

Maximum vapor velocity as a function of shell-tube diameter ratio

Maximum evaporator and condenser NH_3 vapor Reynolds number

Evaporator optimum heat transfer surface area per kWe net as a function of L/D_o

Relationship between shell diameter and tube surface area with tube L/D_o as a parameter

Approximate evaporator shell diameter vs length for one inch diameter tubes

General scaling requirements summary

REQUIREMENTS FOR FLOW SIMILITUDE

1. GEOMETRIC SIMILARITY

RATIOS OF CORRESPONDING DIMENSIONS IN THE MODEL & PROTOTYPE ARE THE SAME.

2. KINEMATIC SIMILARITY

RATIOS OF CORRESPONDING VELOCITIES AND ACCELERATIONS IN THE MODEL AND THE PROTOTYPE ARE THE SAME.

3. DYNAMIC SIMILARITY

RATIOS OF CORRESPONDING FLUID FORCES IN THE MODEL AND THE PROTOTYPE ARE THE SAME.

REQUIREMENTS FOR FLOW SIMILITUDE

The justification for the use of models is an economic one since it is generally cheaper to build and test models of large OTEC components rather than relying entirely on design calculations. In order to obtain complete similarity between the model and prototype, it is necessary that geometric, kinematic, and dynamic similarity exist. Geometric similarity is obtained by maintaining the ratios between corresponding lengths the same in the model as in the prototype. Kinematic similarity requires that ratios of forces acting on corresponding fluid masses be similar in the model and prototype, which gives rise to the requirement of dynamic similarity. In order to obtain dynamic similarity between the model and prototype, it is necessary that all independent force ratios be the same. This is assured for viscous forces by having the Reynolds number the same in the model as the prototype. The ratio of inertial to gravity forces is given by the Froude number, while the ratio of inertial to surface tension forces is given by the Weber number. In most cases it is not necessary to maintain all of the force ratios the same and generally all but one or two can be omitted.

OTEC POWER CYCLE COMPONENT SCALING TECHNOLOGY

COMPONENT	STATE-OF-THE-ART	DIMENSIONLESS NUMBERS & SIMILARITY PARAMETERS
CONDENSATE PUMP	YES	SPECIFIC SPEED, SPECIFIC DIAMETER
SEA WATER PUMP	YES	SPECIFIC SPEED, SPECIFIC DIAMETER
LINE FLOW LOSS		
COLD WATER PIPE	YES	REYNOLDS, E / D
NH ₃ VAPOR & LIQUID	YES	REYNOLDS, E / D
TURBINE	YES	SPECIFIC SPEED, SPECIFIC DIAMETER
CONDENSER	YES (?)	REYNOLDS, PRANDTL, NUSSELT, STROUHAL
EVAPORATOR	NO	REYNOLDS, PRANDTL, NUSSELT, STROUHAL
DEMISTER	NO	REYNOLDS

OTEC POWER CYCLE COMPONENT SCALING TECHNOLOGY

Because of the unusually large size of many of the full-scale OTEC components, it is felt necessary to base the prototype design on subscale test results to provide an assurance of performance not possible through calculations alone. Condensate pumps, sea water pumps, lines, and turbines have extensive sub-scale test histories and this experience should allow fairly accurate prediction of prototype performance based on testing of suitably sized OTEC models. The same is not generally true for the heat exchangers as they are approximately an order of magnitude larger in heat transfer surface area than the largest condenser presently in commercial service. Very little, if any, experience is available for horizontal tube evaporators, which makes sub-scale testing of this component extremely important. The general size of these two components will present heat transfer and fluid flow problems for which there are no precedents.

TURBINE SCALING

- PROCEDURES ESTABLISHED
- LAWS OF SIMILARITY
- SPECIFIC DESIGN CONSTANTS
- DEVIATION

$$\text{SPECIFIC SPEED} = N_S = \frac{N Q^{1/2}}{H^{3/4}}$$

$$\text{SPECIFIC DIAMETER} = D_S = \frac{D H^{1/4}}{Q^{1/2}}$$

$$\text{SPECIFIC HEAD} = H_S = \frac{H}{N^2 D^2}$$

$$\text{SPECIFIC CAPACITY} = Q_S = \frac{Q}{N D^3}$$

$$\text{REYNOLDS NUMBER} = R_N = \frac{V D \rho}{\mu}$$

TURBINE SCALING

Turbine design procedures are similar to pump design procedures and are well developed for hydraulic, steam, and gas turbines. Similarity, considerations show that only four parameters are required to completely describe the characteristics of turbomachines: specific speed, specific diameter, Reynolds number, and Mach number. In general, the important parameters in turbine scaling are specific speed and specific diameter, with Reynolds and Mach number having a second-order influence. In addition, scale effects must be considered when the relative roughness of the model and prototype inner surfaces differ by an appreciable amount.

PUMP SCALING

- CURRENT STATE OF INDUSTRY
- SIMILARITY
- DEVIATION
- SPECIFIC DESIGN CONSTANTS

SPECIFIC SPEED	N_S	$= \frac{N Q^{1/2}}{H^{3/4}}$
----------------	-------	-------------------------------

SUCTION SPECIFIC SPEED	N_{SS}	$= \frac{N Q^{1/2}}{NPSH^{3/4}}$
------------------------	----------	----------------------------------

SPECIFIC HEAD	H_S	$= \frac{H}{N^2 D^2}$
---------------	-------	-----------------------

SPECIFIC CAPACITY	Q_S	$= \frac{Q}{N D^3}$
-------------------	-------	---------------------

SPECIFIC DIAMETER	D_S	$= \frac{D H^{1/4}}{Q^{1/2}}$
-------------------	-------	-------------------------------

SPECIFIC POWER	P_S	$= \frac{HP}{N^3 D^5}$
----------------	-------	------------------------

HEAD COEFFICIENT	ψ	$= \frac{H}{U^2/g}$
------------------	--------	---------------------

FLOW COEFFICIENT	ϕ	$= \frac{C_M}{U}$
------------------	--------	-------------------

PUMP SCALING

The same general similarity considerations which apply to turbines also applies to pumps. In addition it is necessary to account for cavitation in the condensate and reflux pumps, which is scaled by the suction specific speed. The sea water pumps are scaled by specific speed and specific diameter with suitable corrections for roughness effects. The state-of-the-art for pump model testing is well developed and should allow suitable prototype designs to be specified on the basis of model dimensions on the order of one-fifth those of the prototype.

TURBINE AND SEA WATER PUMP DIAMETER AND SPEED AS A FUNCTION OF NET POWER

TURBINE AND SEA WATER PUMP DIAMETER AND SPEED AS A FUNCTION OF NET POWER

Model testing performed at the same head and similarity parameters of specific speed and specific diameter as the prototype yields the following relationships between rotational speed and power and diameter and power:

$$N_m/N_p = \sqrt{P_p/P_m} \quad , \quad D_m/D_p = \sqrt{P_m/P_p}$$

These relationships are shown as a function of the net electrical OTEC power indicating the model sizes and speeds for various test facility sizes. Decreasing power level requires an increase in speed with an attendant increase in dimensions given by the relationship $(ND)_m = (ND)_p$. In order to obtain similar Reynolds numbers for both the model as well as the prototype, it would be necessary to choose a test fluid with a kinematic viscosity given by $\nu_m = \nu_p (D_m/D_p)$, which would not be practical for the sea water pumps but strongly suggests the use of air for turbine model testing where a suitable ammonia source is not presently available.

METHODS OF PREDICTING FULL SCALE PUMP EFFICIENCY FROM MODEL PUMP DATA

E-14

METHODS OF PREDICTING FULL-SCALE PUMP EFFICIENCY FROM PUMP MODEL DATA

A number of empirical equations have been derived from an accumulation of pump performance data over a span of about 50 years, the oldest being the Moody equation and the most recent being the modified Moody equation. The German Din equation is used widely in Europe and the Casandy-Rutschi equation was an attempt at improving it. The modified Moody is based on the experience of an American pump contractor. Three of the equations show excellent agreement down to a scale factor of 0.25, below which they diverge rapidly. The chart indicates that below a scale factor of 0.2 the extrapolation of model efficiency to full scale becomes judgmental and reflects the confidence of the individual pump designer.

EVAPORATOR DESIGN

E-16

SECTION A-A

EVAPORATOR DESIGN

The evaporator and condenser are similar in tube bundle design, being composed of horizontal tubes through which sea water is pumped at a velocity of approximately 6 ft/sec. The basic difference is in the shell where provision must be made to receive the turbine exhaust for the condenser and the manner of drawing off the vapor in the evaporator. The condenser must also provide for the removal of noncondensable gases which could enter the system through dissolved air in sea water from condenser leaks and gas produced through chemical reactions or dissociation of ammonia. Vapor removal from the evaporator will occur through holes in the shell, as shown in the figure. In addition, provision must be made to introduce the liquid ammonia to the evaporator tubes in a manner which will ensure that no dry areas exist while maintaining refluxing at a minimum. The present concept is to use the topmost tube in each column of tubes as a liquid ammonia distribution tube with the flow rate being dependent on the number of tubes in the column. The full condensate pump flow would be used to supply this set of distribution tubes while any required reflux would be circulated from the evaporator sump to a horizontal row of tubes located approximately one-third to half way up the tube bundle.

The sea water heat transfer and pressure loss are readily calculated and determination of the thermal resistance associated with the sea water and tube conduction will be generally independent of the power rating of the heat exchanger. Prediction of the vapor side heat transfer presents a serious problem for the evaporator and to a lesser extent for the condenser, where both of these values will be dependent on the heat exchanger rating and design.

MAXIMUM EVAPORATOR MASS RATE AS A FUNCTION OF SHELL DIAMETER

E-18

MAXIMUM EVAPORATOR MASS RATE AS A FUNCTION OF SHELL DIAMETER

The maximum liquid flow rate occurs on the top tubes of any column of evaporator tubes, decreasing to a minimum as liquid is evaporated from the falling film during its passage down the column of tubes. For any particular value of pitch-to-diameter ratio and average tube column heat flux, the maximum flow rate on the centerline column of tubes is proportional to the tube bundle diameter for the type of liquid distribution system presently being considered. Since the evaporation and condensation heat transfer coefficients are functions of the liquid film flow rate, exact simulation of the vapor side heat transfer requires testing with the prototype tube bundle diameter. Since full-scale testing of the heat exchangers is not generally feasible, simulation of the vapor side heat transfer process will be difficult.

VARIATION OF NH_3 EVAPORATOR FEED-LINE ORIFICE DIAMETER

VARIATION OF NH_3 EVAPORATOR FEED-LINE ORIFICE DIAMETER

Design of the evaporator liquid distribution lines requires selection of a line diameter, orifice pressure drop, orifice diameter, and spacing which will ensure a uniform liquid film on each column of evaporator tubes. In addition, the minimum orifice size will be constrained by the maximum level of contamination which will exist in the system during operation. The relationship between orifice diameter and flow rate per unit length is shown for various hole spacings for an orifice pressure drop of 10 psi. Use of a 2-psi pressure drop will increase the orifice diameter values by approximately 50%. The lower flow rate values associated with sub-scale heat exchangers will require a choice between minimum orifice diameter and orifice hole spacing (n/L). One possible means being considered to alleviate the orifice plugging problem is to locate the orifice holes along the top of the distribution tube with suitable flow diverters.

COMPARISON OF VERTICAL AND HORIZONTAL VAPORIZATION HEAT TRANSFER COEFFICIENTS

COMPARISON OF VERTICAL AND HORIZONTAL VAPORIZATION HEAT TRANSFER COEFFICIENTS

Falling film evaporators have generally tended to be of the vertical surface type while very little experience is presently available for the horizontal tube evaporator design currently being considered for OTEC. Chun and Seban have presented a correlation for heat transfer to vertical evaporating liquid films which is in good agreement with experimental data for water over a wide range of Reynolds and Prandtl numbers. There is only a very limited amount of data for evaporation heat transfer from horizontal tubes and most of that is for water. The data of Fletcher, et al for water on 1- and 2-in. horizontal tubes is compared with the Chun-Seban correlation indicating some improvement over the vertical tube case. Some of the higher values of heat transfer coefficient shown are the result of nucleate boiling in the liquid film. The limited data presently available indicate that the heat transfer coefficient is independent of tube diameter.

OVERALL HEAT TRANSFER COEFFICIENT VS SEA WATER VELOCITY

CHANGE OF PHASE HEAT TRANSFER COEFFICIENT AS A PARAMETER

OVERALL HEAT TRANSFER COEFFICIENT VS SEA WATER VELOCITY

The relative influence of sea water velocity and ammonia side heat transfer coefficient on the overall heat transfer coefficient is shown for a 2-in. tube with mild fouling. Present operating conditions are for a water velocity of approximately 6 ft/sec at an assumed average shell side heat transfer coefficient of 1500 Btu/hr ft²°F. Since the tube shell side thermal resistance is only one quarter of the total, relatively large variations in its absolute value produce relatively small changes in the overall heat transfer coefficient. This will remain essentially true for most cases unless sea water side enhancement is employed to decrease the percentage of thermal resistance associated with the sea water side heat transfer coefficient.

CHEN'S EXPRESSION FOR LAMINAR FILM CONDENSATION ON HORIZONTAL TUBES

CHEN'S EXPRESSION FOR LAMINAR FILM CONDENSATION ON HORIZONTAL TUBES

The variation of ammonia condensation heat transfer coefficient as a function of Reynolds number is shown for Chen's analysis of laminar film condensation on horizontal tubes. Also indicated on the abscissa is the approximate maximum ammonia flow rate (Γ) on the bottom row of tubes in lbm/hr-ft. The improvement in heat transfer coefficient indicated for a 200-tube column results from a consideration of condensation occurring between tubes. Experimental data appear to confirm inter-tube condensation with fair agreement between the data and Chen's approximate theory. The dotted line for turbulent film condensation is based on an analysis by Chun and Seban for a vertical surface.

RELATIONSHIP BETWEEN Γ & NUMBER OF TUBES FOR CONDENSING AMMONIA AT 50 F

RELATIONSHIP BETWEEN MASS FLOW RATE AND NUMBER OF TUBES FOR CONDENSING AMMONIA .

Using Chen's heat transfer correlation and a particular sea water velocity allows determination of the total condensing rate for a column of "n" tubes. The variation of mass flow rate with the number of tubes is given by the average ammonia film temperature shown as the operating line, which indicates that a vertical column of 100 tubes, 1-ft in width will condense approximately 200 lbm/hr. A slight enhancement in the condensation heat transfer coefficient will arise through the proposed 15-deg inclination to the horizontal and other methods should also be investigated to improve the shell side thermal resistance.

COMPARISON OF OTEC HEAT EXCHANGER REQUIREMENTS WITH CURRENT TECHNOLOGY

COMPARISON OF OTEC HEAT EXCHANGER REQUIREMENTS WITH CURRENT TECHNOLOGY

A comparison of current condenser heat exchanger technology with OTEC requirements indicates that the 3, 6, and 9 MW_e units are within the range of current capability, while the prototype heat exchangers will be approximately a factor of 10 larger than the largest heat exchanger now in existence. Many problems remain to be resolved for these heat exchangers and in particular for the evaporator for which almost no experience is available. A few major problems requiring immediate attention are ammonia flow distribution, refluxing rates, heat transfer coefficients, tube wetting, and vapor-liquid entrainment.

CRITICAL VAPOR VELOCITY FOR TUBE VIBRATION

CRITICAL VELOCITY FOR TUBE VIBRATION

Heat exchanger tube vibration generally results from phased shedding of vortices where the frequency of vortex shedding coincides with a natural frequency of the tubes. The vortex shedding frequency is characterized by the Strouhal number, which is the product of vortex shedding frequency and tube outside diameter divided by the maximum velocity between tubes. A Strouhal number of 0.23 has been assumed to be representative of the present conditions and used to generate the curves for critical vapor velocity shown in the figure. Baffle spacing is presently on the order of 7 ft, which gives a span L/D_o of 42 for a 2-in. tube and a critical velocity on the order of 25 ft/sec.

MAXIMUM VAPOR VELOCITY AS A FUNCTION OF SHELL-TUBE DIAMETER RATIO

MAXIMUM VAPOR VELOCITY AS A FUNCTION OF SHELL-TUBE DIAMETER RATIO

The maximum vapor velocity occurs between tubes on the periphery of the tube bundle for both the evaporator and condenser resulting from vapor evaporated or condensed within the bundle. For a particular total mass rate to surface area and pitch to diameter ratio, it can be shown that the maximum vapor velocity is a function of the tube shell diameter to tube diameter ratio. Maximum velocity variation with the diameter ratio is shown for two values of overall heat flux taken to be representative of the evaporator and condenser. Predicted values for the prototype appear to be well below the critical value of 25 ft/sec based on a Strouhal number of 0.23. Similar maximum velocities can be obtained in the subscale heat exchangers by maintaining geometric similarity, $(D_s/D_o)_m = (D_s/D_o)_p$. It is also possible to increase the velocity by increasing the overall heat transfer rate through an increase in the log mean temperature difference.

MAXIMUM EVAPORATOR & CONDENSER NH₃ VAPOR REYNOLDS NUMBER

AS A FUNCTION OF SHELL DIAMETER WITH $\bar{U}_O \Delta T_{OLM}$ AS A PARAMETER

MAXIMUM EVAPORATOR AND CONDENSER AMMONIA VAPOR REYNOLDS NUMBER

The maximum vapor Reynolds number occurs at the same location as the maximum vapor velocity described previously and is given by $Re = V_{\max} \rho D_o / \mu$. Making the appropriate substitutions produces the relationship shown in the figure where the Reynolds number is proportional to shell diameter and overall average heat flux. Scaling viscous forces, therefore, is only possible where the subscale test has the same tube bundle diameter as the prototype. This can be accomplished by shortening the length to provide the required heat transfer surface at the expense of fabrication and testing cost. It will also be seen that the flow is turbulent over most of the tube bundle for the various diameters presently being considered. When choosing a subscale heat exchanger diameter it will be necessary to trade off the benefits of dynamic scaling vs the associated manufacturing and testing costs.

EVAPORATOR OPTIMUM HEAT TRANSFER SURFACE AREA PER KW_e NET AS A FUNCTION OF L/D_o

EVAPORATOR OPTIMUM HEAT TRANSFER SURFACE AREA PER KW_e NET AS A FUNCTION OF L/D_o

Consideration of tube bundle heat transfer and pumping power penalties to determine the surface area per unit net power produced has shown the latter to be primarily a function of tube length to diameter ratio for any particular value of average shell side heat transfer coefficient. The resulting curves indicate that the area per unit net power value is relatively insensitive to L/D_o over the range $50 < L/D_o < 200$, which provides a rather wide latitude for the choice of subscale tube length and diameter.

RELATIONSHIP BETWEEN SHELL DIAMETER AND TUBE SURFACE AREA WITH TUBE L/D_o AS A PARAMETER

RELATIONSHIP BETWEEN SHELL DIAMETER AND TUBE SURFACE AREA WITH TUBE L/D_o AS A PARAMETER

The relationship between heat exchanger tube shell diameter and total external surface area is shown in the accompanying figure with tube L/D_o as a parameter. Also indicated are the approximate evaporator or condenser heat transfer surface areas for three net power levels. The range of subscale shell diameters for the three net power levels is clearly indicated by the curves for $L/D_o = 50$ and 200. The corresponding tube lengths are also shown for 1- and 2-in. tube diameters. Choice of a shell diameter of 35 ft for the 9-MW case gives an L/D_o of approximately 200, which is within the desired range. By choosing 1-in.-diameter tubes, it is possible to achieve geometrical similarity and provide a good model for the simulation of tube vibration problems. Baffle spacing would also have to be reduced to approximately half that for the prototype with an overall tube bundle length of approximately 16 ft.

APPROXIMATE EVAPORATOR SHELL DIAMETER VS. LENGTH FOR ONE INCH DIA. TUBES

APPROXIMATE EVAPORATOR SHELL DIAMETER VS LENGTH FOR 1-IN.-DIAMETER TUBES

These curves present the relationship between shell diameter and length for 1-in. -diameter tubes and three net power levels.

GENERAL SCALING REQUIREMENTS SUMMARY

<u>COMPONENT</u>	<u>PHYSICAL REQUIREMENTS FOR SCALING</u>	<u>LIMITS</u>
CONDENSATE PUMP	SPECIFIC SPEED AND DIAMETER SAME FOR MODEL & PROTOTYPE	$D_M/D > 0.2$
SEA WATER PUMP	SPECIFIC SPEED AND DIAMETER SAME FOR MODEL & PROTOTYPE	$D_M/D > 0.2$
TURBINE	SPECIFIC SPEED AND DIAMETER SAME FOR MODEL & PROTOTYPE	$D_M/D > 0.2$
LINE FLOW LOSSES	FLOW REYNOLDS NUMBER & ϵ/D SAME FOR MODEL & PROTOTYPE	NONE
EVAPORATOR	SHELL DIAMETER SAME FOR MODEL & PROTOTYPE	TEST FACILITY
CONDENSER	SHELL DIAMETER SAME FOR MODEL & PROTOTYPE	TEST FACILITY

GENERAL SCALING REQUIREMENTS SUMMARY

Modeling of the pumps and turbine should not present a problem as long as the dimensional scale factor does not go below approximately 0.2. This value is somewhat arbitrary and represents a general minimum in use within the industry. There are additional requirements imposed on the condensate and evaporator reflux pumps in order to preclude cavitation which requires operation at the same net positive suction head in the model as in the prototype.

Line flow losses are completely predictable although the choice of flow conditions should provide conditions similar to the prototype. It would also be advantageous to scale the line capacitance to correctly model the dynamic effects of changes in flow rates and conditions for the cycle test simulation.

Scaling of the heat exchangers requires a model with the same shell diameter as the prototype in order to provide similitude in the liquid distribution system, shell side heat transfer coefficient, vapor-liquid entrainment, vapor pressure drop, and refluxing. Choice of a suitable model shell diameter must take into consideration the cost of manufacturing and testing vs technical benefits in order to arrive at the "optimum" model size.

TESTING I - AR & T - COMPONENTS

PRESENTED BY
B. L. MESSINGER

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING I – AR&T – COMPONENTS

Testing I definition – AR&T

Testing I definition – major components

Testing I objectives

AR&T heat transfer tests

Static helical insert

Advanced research & technology – heat transfer enhancement

AR&T – evaporator surface nucleation mechanism

NH₃ evaporation & condensation enhancement

AR&T – non-heat transfer testing

AR&T – turbine performance

AR&T – materials

AR&T – electrical transmission

AR&T – chemical energy utilization

Advanced research & technology schedule

AR&T recommendations

Testing I objectives – major components

Component list for testing in ERDA facilities

Land based large heat exchanger test facility

Heat pump-water tunnel

LBTF heat exchanger test bed schematic

P-H diagram of OTEC exchanger component test

Heat exchanger test article concept

Tube bundle segmental test concept

Heat exchanger development (schedule)

Regenerative gas-phase (wet) turbine test

LBTF ammonia turbine test bed schematic

Land-based OTEC turbine test capability

Ammonia turbine test pressure-enthalpy diagram

Ammonia turbine development (schedule)

Component list for testing at vendor facilities

Component list for hydrodynamic testing

Component test – preliminary conclusions

TESTING I – DEFINITION

ADVANCED RESEARCH & TECHNOLOGY

IDENTIFY AR & T TESTING REQUIREMENTS (LIMITED SCALE)

- MAJOR TECHNICAL DISCIPLINES:
 - HEAT TRANSFER (SINGLE AND TWO-PHASE)
 - THERMODYNAMICS (POWER CYCLES)
 - FLUID MECHANICS (PRESSURE LOSS)
 - MARINE BIOLOGY (FOULING - SEA - BASED)
 - ENGINEERING CHEMISTRY (MATERIALS)

TESTING I - DEFINITION: AR&T

Advanced Research & (Advanced) Technology (AR&T) will consist of both analytical and experimental early and on-going activities generally on a small scale in the disciplines indicated. Many of the test programs in this category will be conducted in presently existing facilities such as government-owned laboratories and university or contractor-owned laboratories. The subsequent on-going development of basic improvements in the technology of OTEC may be conducted in dedicated facilities in close proximity to component and system development test facilities.

TESTING I—DEFINITION

MAJOR COMPONENTS

- IDENTIFY LAND-BASED POWER PLANT COMPONENT TEST FACILITY REQUIREMENTS:
 - EVAPORATOR TESTS
 - CONDENSER TESTS
 - POWER TURBINES
 - AMMONIA PUMPS
- IDENTIFY SEA-BASED COMPONENT TEST FACILITY REQ'TS.
 - EVAPORATOR
 - CONDENSER
 - SEAWATER PUMPS

TESTING I - DEFINITION: MAJOR COMPONENTS

Test facilities to be defined for major OTEC components will, in general, encompass capabilities which, because of the resources and space required for their operation, are not presently available in existing laboratories. These will fall into two general categories: land-based and sea-based. A current estimate of which major components will require such special facilities are listed in the chart. In the case of heat exchangers, the difference in size levels between a land-based and sea-based facility is due entirely to practical constraints involved in the required warm and cold water thermal resources.

TESTING 1 - OBJECTIVES

AR & T:

- VALIDATE NEW CONCEPTS
- DEVELOP CORRELATIONS OF TEST DATA
- PROVIDE PRELIMINARY DESIGN DATA
- DEFINE PRELIMINARY COST IMPACTS

TESTING I - OBJECTIVES: AR&T

The primary objective of OTEC AR&T is to test and evaluate any concepts which have potential for improved performance and reduced power costs.

Test data acquired in such testing must be correlated to permit their early application to design or redesign of the OTEC power cycle or subsystems.

The value of such tested concepts must be established in terms of potential cost reductions.

AR&T HEAT TRANSFER TESTS

AREAS OF MAJOR INTEREST

SEAWATER SIDE:

- STATIC & DYNAMIC HEAT TRANSFER ENHANCEMENT DEVICES
- FOULING COUNTER MEASURES (CHEMICAL & MECHANICAL)
- ΔP PENALTIES (PARASITIC POWER)
- COST IMPROVEMENTS (SURFACE AREA REDUCTION)

SHELL OR NH_3 SIDE:

- TUBE SURFACE IRRIGATION TECHNIQUES
ORIENTATION (SLOPE), FLUTING (VERTICAL),
PITCH/DIA. RATIO & SQUARE VS STAGGERED
- NUCLEATING SURFACE EFFECTIVENESS IN THIN LIQUID FILM.
- LIQUID ENTRAINMENT SUPPRESSION
- GRAVITY VS SHEAR-CONTROLLED LIQUID FLOW

AR&T TESTS: HEAT TRANSFER

Although AR&T testing will apply to a wide range of technical disciplines, the specific examples cited are presently of major interest in the field of heat transfer enhancement, which in turn is considered to have the greatest potential for reducing the cost of OTEC plant and power.

STATIC HELICAL INSERT

TRANSFER ENHANCEMENT: STATIC HELICAL INSERTS

Static helical inserts for the single-phase sea water side of the heat transfer tubes have been considered by LMSC from the beginning of the OTEC study program. This class of device is not novel and some data have been in the literature for many years, but the detailed evaluation for an OTEC application would require an experimental determination of the optimum helical pitch in terms of the ratio of heat transfer improvement to net pumping power increase. Another potential advantage of these inserts is the possible inclusion of chemical anti-fouling elements or compounds in the material formulation (for example, metallic copper).

ADVANCED RESEARCH & TECHNOLOGY

SEA WATER HEAT TRANSFER ENHANCEMENT TWISTED RIBBON-FLOW ACTIVATED ROTATION

AR&T: FLOW-ROTATED SEA WATER HEAT TRANSFER ENHANCEMENT

A dynamic form of helical insert is the flow-rotated twisted ribbon (disclosed by W. R. Penny and independently by H. H. Sephton). The peripheral edges of this device continuously disturb and disrupt the boundary layer zone of the water flow passage. Because of this action, the device has the potential for performing a dual function: heat transfer enhancement and inhibition of biofouling of the sea water side of the tube surface.

As of this date, no known data are available on this application of the device. It is therefore a candidate for early AR&T testing. (Dr. Sephton has submitted a proposal to conduct such tests at the University of California.)

ADVANCED RESEARCH & TECHNOLOGY EVAPORATOR SURFACE NUCLEATION MECHANISM

HORIZONTAL TUBES

AR&T: EVAPORATOR SURFACE NUCLEATION MECHANISM

Special nucleating surface treatments have been proven effective in enhancing boiling liquid heat transfer coefficients primarily in submerged or pool-boiling. In the extremely large OTEC evaporators, pool boiling cannot be effective unless complex subdivisions of the vapor space are accepted. As an alternative, thin-film evaporation is planned in the LMSC evaporator design and there remains the question of whether thin film mass transfer rates can be further enhanced by the same nucleation surface treatment used in pool boiling. A further potential benefit yet to be evaluated is the film distribution (capillary action) enhancement available from this surface treatment.

Of related interest in this field of research is the inter-action which takes place between the gravity-controlled liquid flow and the vapor shear-controlled flow in tube bundle fields.

NH₃ EVAPORATION & CONDENSATION ENHANCEMENT

VERTICAL TUBES

AR&T: AMMONIA SIDE HEAT TRANSFER ENHANCEMENT

Two-phase evaporation and condensation heat transfer enhancement for vertical tubes has been claimed possible by use of longitudinally fluted tubes. Although the evidence for such claims is very convincing for condensation of water (in desalination plants), little, if any, evidence of this is available for either condensation or evaporation of ammonia. Research experiments in this regime will be required. These are further examples of tests which can be conducted in single, or small groups of, tubes in existing facilities.

ADVANCED RESEARCH & TECHNOLOGY

NON-HEAT TRANSFER TESTING

<u>ITEM</u>	<u>EXPERIMENT</u>
TURBINE	EFFICIENCY VS QUALITY & CONFIGURATION
MATERIALS	FOULING, CORROSION, & STRENGTH
PRODUCIBILITY	METALS & PLASTICS
ELECTRICAL TRANSMISSION	CABLE, CONNECTOR, & RISER
CHEMICAL ENERGY UTILIZATION	UNIQUE PROCESS DEVELOPMENT

AR&T: NON-HEAT TRANSFER TESTING

In addition to AR&T testing in the field of heat transfer, a number of other aspects of OTEC design will require experimental evaluation of small-scale test samples. Turbine efficiency is of major concern, particularly as affected by the thermodynamic properties of the working fluid, for example, ammonia. For this phase, the testing can utilize small-scale turbines (as small as 1/10 scale). Materials of construction must be evaluated in the appropriate operating environment. Producibility research is aimed at cost and schedule reduction.

Applied research is required in the field of electrical transmission to extend the offshore range for the hard-wire conduction of very high power loads. Separate investigations should be made for the cable insulation and armor, the underwater connector, and the increased strength required for the riser from the ocean floor to the plant.

Past and on-going studies for the utilization of the OTEC plant electrical energy have involved known products and processes. These studies should be supplemented by laboratory experiments to develop unique processes, or new products, or to solve problems associated with installing existing processes in the OTEC complex.

ADVANCED RESEARCH & TECHNOLOGY

TURBINE PERFORMANCE

TURBINE EFFICIENCY VS

- WORKING FLUID PROPERTIES
- QUALITY
- WATER CONTENT
- HEAD
- SPEED
- FLOW RATE

AR&T: TURBINE PERFORMANCE

The criticality of turbine performance is reflected by the fact that a 1% change in turbine efficiency results in a change of approximately 1.3% in net power output. Little data exist on the performance of turbines operating with ammonia vapor, and OTEC power plant performance is based on estimates provided by several turbine vendors.

Relative performance improvements, using ammonia as the working fluid, can be accomplished on small-scale models. Baseline data will be obtained for the configuration utilized in the cycle plant turbine development program and performance improvements evaluated from this baseline.

Complete performance maps will be obtained as functions of the working fluid properties (pressure and temperature), variations in flow quality, flow rate and water content. Characteristic data will be in terms of turbine efficiency versus speed and head (pressure ratio).

ADVANCED RESEARCH & TECHNOLOGY

MATERIALS

EXPERIMENT

FOULING

CORROSION

VARIABLES

- TUBES, PLATES, SCREENS
- ANTIFOULANTS
- COMPOSITION
- DEPTH, CURRENT, DURATION..
- GEOGRAPHICAL SITES
- METAL ALLOY
- METAL COATINGS
- CATHODIC PROTECTION

AR&T: MATERIALS

Research in three basic categories is proposed to improve the performance and to extend the life and reliability of the OTEC components.

The fouling tests should evaluate the candidate materials for the tubes, screens, plates, and rotating machinery components. Tests should be conducted at potential OTEC sites at representative depths to sense the actual marine environment. It is essential that the marine biota be identified at each test site and test depth and the influence of their presence on heat transfer be determined. Concurrent tests would evaluate the benefits of various chemical countermeasures. Both static and fluid flowing tests would be required for a complete evaluation. The static tests could be accomplished by suspending coupons from a buoy. Fluid flow tests could be simulated by raising and lowering samples through a relatively narrow range about a prescribed depth.

The corrosion tests can be conducted at the same sites as above with these samples developed specifically for corrosion prevention. Laboratory analyses shall determine the depth and rate of corrosion as a function of time. Certain of these specimens will be analyzed and tested to determine any degradation in strength due to stress corrosion. The fouling and corrosion experiments are being initiated by Battelle, N. W.

ADVANCED RESEARCH & TECHNOLOGY

ELECTRICAL TRANSMISSION

CABLE

- INSULATION
- ARMOR
- FLEXIBILITY

CONNECTOR

- SWIVEL
- SEALS
- WET OR DRY

RISER

- STRENGTH
- FLEXIBILITY

AR&T: ELECTRICAL TRANSMISSION

Understanding breakdown mechanisms in dielectrics and improved techniques for exclusion of seawater are required to allow predictable long-duration fault-free cable life at extreme depths. Cables must be lighter and stronger to extend laying capability to extreme depths, requiring advances in armor to improve strength-to-weight ratio and to eliminate twist resulting from spiral-wound cable construction. Improved flexibility is needed to alleviate stress where the cable is unreeled and as it meets the sea floor.

Connectors are needed to join sea floor cable to riser and riser to platform, and will be incorporated in the swivel, which is used with single-point mooring. Reliability of connectors and swivel for high voltage and current depends particularly on seals to retain dielectric and exclude seawater. Applications exist for both wet (submerged makeup) and dry connector types.

The riser has particularly stringent strength and flexibility requirements since it is suspended from platform to sea floor, perhaps without additional support, and is subject to continual flexing as the platform moves. Advances in conductors, dielectrics, sheaths, and armor are required to avoid fatigue failure over the design life of the riser cable.

ADVANCED RESEARCH & TECHNOLOGY

CHEMICAL ENERGY UTILIZATION

<u>ITEM</u>	<u>OBJECTIVE</u>
UNIQUE PRODUCT	ENERGY INTENSIVE PROCESS
RECYCLABLE ENERGY CARRIER	PROCESS CYCLE EFFICIENCY
ELECTROLYZERS	ECONOMY, COMPACTNESS

AR&T: CHEMICAL ENERGY UTILIZATION

Research into the utilization of OTEC electrical energy will involve a continued search for unique production requiring an energy intensive process. These could be produced using only raw materials taken from the sea or the atmosphere, (e.g., hydrogen and ammonia) or may import feedstocks as for the production of plastics, fertilizers, or aluminum.

A second approach is to develop a recyclable energy carrier which has a high cycle efficiency. This could be accomplished by a disassociation/association reaction, (e.g., hydrogen chloride) a hydration, or a change of state.

Research into electrolyzers is necessary to improve process efficiency and provide for more compact systems for large volume production.

ADVANCED RESEARCH & TECHNOLOGY SCHEDULE

AR&T: SCHEDULE

The schedule shown indicates the anticipated approach to AR&T investigations. Since the sea water side heat transfer coefficient and the sea water side biofouling appear to be the primary areas in which performance gains can be made, these efforts will be undertaken first. Working fluid dynamics and heat exchanger geometry studies will be initiated sequentially at 1-month intervals. Ammonia turbine development and energy utilization investigations will begin in the third month and heat exchanger producibility studies undertaken as required throughout the program.

It is assumed that prior activities will permit the establishment of the test requirements for the heat transfer enhancement and fouling studies at the outset of the program. The facility or site, at which the testing will be done, and the vendor, for the ammonia turbine development, will be selected within 3 months after the test requirements are established. Design and fabrication of the test apparatus will be accomplished in each subsequent 6-month period, as indicated, and detailed test plans will be provided prior to the actual test period.

Model fabrication and testing periods are shown sequentially for the individual efforts within an AR&T subject. It may be advisable, particularly in the heat exchanger study efforts, to accelerate the model fabrication efforts and conduct the tests simultaneously.

As indicated by the dashed continuation lines, AR&T efforts will continue throughout the program as long as new schemes are proposed.

AR&T RECOMMENDATIONS

- INITIAL AR&T EFFORTS SHOULD BE CONDUCTED IN EXISTING OR MODIFIED GOVERNMENT-, CONTRACTOR- OR INSTITUTION-OWNED FACILITIES.
- LABORATORY SPACE ALLOCATED IN PROPOSED TEST FACILITY FOR AR&T EFFORTS IN SUPPORT OF FACILITY ACTIVITIES.

AR&T RECOMMENDATIONS

In order to expedite the AR&T efforts and integrate the results into the downstream program in a cost-effective manner, available laboratories at Government, Contractor, University and Research Institute facilities should be utilized. The test programs can be initiated as soon as authorization is received.

Future efforts may indicate the desirability of conducting AR&T investigations at the completed test facility from the standpoints of cost, schedule and physical proximity. Space has therefore been allocated for the construction of laboratories for undertaking these activities.

TESTING 1 - OBJECTIVES

MAJOR COMPONENTS:

- EXTEND CURRENT DESIGN EXPERIENCE
- VERIFY DESIGN PERFORMANCE
- LARGE SCALE VERIFICATION OF AR & T CONCEPTS
- PROVIDE MEANS FOR DIAGNOSTIC "DEBUGGING" OF CONCURRENT CYCLE OR PILOT PLANT DEFICIENCIES
- IDENTIFY AREAS FOR FUTURE AR & T

TESTING I - OBJECTIVES MAJOR COMPONENTS

Testing of major components will provide an early opportunity for acquiring large-scale design experience in test article design and fabrication.

The test programs will have the objective of verifying the design performance and related characteristics.

These test articles will provide the first opportunity for full or large scale proving of AR&T-developed innovations.

After the cycle plant and pilot plant go into operation, specific operating problems can be diagnosed and overcome by simulating them in the major component test facility.

Experience in the major component test facility will provide a means for defining needs for further AR&T.

COMPONENT LIST FOR TESTING IN ERDA FACILITIES

COMPONENT	PROBLEM	PROJECTED SCALE FACTOR	CONFIDENCE LEVEL
HEAT EXCHANGERS	HEAT TRANSFER COEFFICIENT	0.25 MW	0.75 - 0.85
HEAT EXCHANGERS	HEAT TRANSFER COEFFICIENT	2.5 MW	0.80 - 0.90
PUMP, SEA WATER	EFFICIENCY, FLOW RATE	FULL SIZE	0.99
TURBINE	EFFICIENCY, TWO PHASE FLOW	FULL SIZE	0.99
CONTROL SYSTEM	INTEGRATION, SENSITIVITY	COMPLETE BREADBOARD	0.99

COMPONENT LIST FOR TESTING IN ERDA FACILITIES

The cycle components shown present test requirements which cannot be met in available facilities. These requirements are associated with working fluid flow rates and thermal resources for heat exchanger testing, working fluid vapor flow rates for turbine testing, and sea water flow rates for pump testing. This latter flow requirement of approximately 1.6×10^6 gpm suggests that sea water pump testing be accomplished in an ocean environment.

While the performance of the control system can be synthesized at a vendor's facility, the first opportunity to determine control system interactions and responses will be during the testing of the various system components. The OTEC power plant control system will be utilized in conjunction with the facility control system to determine response characteristics and control capabilities.

The confidence level shown is a subjective assessment of the probability of attaining the predicted performance with the indicated level of testing.

LAND BASED LARGE HEAT EXCHANGER TEST FACILITY

DESIRABLE DESIGN FEATURES

- NOT DEPENDENT ON LARGE EXTERNAL
WARM AND COLD WATER RESOURCES (SITE INDEPENDENT)
- SHOULD ACCOMMODATE:
 - 1) HORIZONTAL SHELL & TUBE
 - 2) VERTICAL SHELL & TUBE
 - 3) SERPENTINE TUBULAR COILS OR PANELS
 - 4) DIRECT DUCT-CONNECTED WATER FLOW
 - 5) GRAVITY ACTIVATED WATER FLOW.
- THERMAL RATING SUFFICIENT TO EVALUATE LARGE
SCALE SHELL-SIDE CHARACTERISTICS OF EVAPORATORS
AND CONDENSERS.

LARGE HEAT EXCHANGER TEST FACILITY

For testing large OTEC heat exchanger segments, the most significant facility requirements are those involved in warm and cold water resources. These requirements are much more difficult to meet in a land-based facility than on a mobile sea-based facility wherein the facility can be moved to the locale of the resources. Any land-based test facility which avoids the dependency on natural or artificial sources of warm and cold water is therefore not constrained with respect to location.

The facility should be designed with sufficient flexibility to accommodate a variety of candidate forms of evaporators or condensers.

HEAT PUMP - WATER TUNNEL

Q_{IN} PER MW
 = 38,000 BTU/SEC
 = 11,400 TONS REFRIG'N
 = 1630 H.P.

LARGE HEAT EXCHANGER TESTING - HEAT PUMP-WATER TUNNEL

The initial concept for closed water loop testing of large segments of OTEC heat exchangers was described at the kick-off meeting of the current contract in January 1976. It consisted of a simple recirculating water tunnel in which a test evaporator and condenser were operated in series and interconnected on the NH_3 side by a high (C.O.P.) performance reversed refrigeration cycle or heat pump. In this initial concept, the emphasis for exact simulation of OTEC conditions was associated primarily with the evaporator while accepting some level of compromise for simulation of condenser conditions. The thermodynamic disparity between a heat pump cycle and a power cycle was accounted for by direct water mass flow exchange in the water loop.

LBTF HEAT EXCHANGER TEST BED SCHEMATIC

LBTF HEAT EXCHANGER TEST BED

The final version of the closed water loop test facility introduced the idea of precise OTEC simulation of both evaporator and condenser operating conditions achieved in separate sequential runs of the single facility. In this way the test heat exchangers alternate their functions -- first as OTEC test samples and then as facility heat exchangers. When operating in the latter mode, each heat exchanger is permitted to operate far from its design point conditions as necessary to balance the circuit. For the latter function, the externally cooled liquid subcoolers are employed. To extend the range of test conditions, it is probable that certain minor changes in the schematic will include the ability to extract heat from the NH_3 circuit between the compressor and condenser as well as upstream of the evaporator as presently indicated.

P-H DIAGRAM OF OTEC EXCHANGER COMPONENT TEST

P-H DIAGRAM OF OTEC HEAT EXCHANGER COMPONENT TEST

This outline pressure-enthalpy composite diagram has been drawn to show how, by shifting the counterclockwise heat pump cycle up and down on the temperature scale, the ammonia state points of the clockwise power cycle can be precisely simulated.

Variable sub-cooling of liquid ammonia is indicated by the multiple vertical paths at the left. The OTEC turbine operating line is shown by a dotted line connecting the blacked-in entrance and exit state points. To establish steady state operating conditions in a closed water loop of this type the water temperature rise in the condenser and in the circulating pump must be precisely balanced by the water temperature drop in the evaporator. Since the NH_3 flow rate is identical for both evaporator and condenser, the NH_3 enthalpy change must be nearly identical for both heat exchangers except for the small differential (1.5%) due to the energy input of the water pump. The proposed compressor aftercooling heat exchanger will probably be the most efficient means of controlling this balance. This part of the process is indicated by the B-B' or B-D segments of the upper heat pump cycle.

HEAT EXCHANGER TEST ARTICLE CONCEPT

HEAT EXCHANGER TEST ARTICLE CONCEPT AND SIZING

This diagram illustrates, to approximate scale, a concept for simulation of the significant two-phase flow and heat transfer variables of a full-scale evaporator tube bundle using a small fraction of the total shell cross-sectional area. Shown superimposed on the LMSC baseline shell diameter are two projected sizes of square tube-bundles: One equivalent to 0.25 MW_e output having a 4 ft x 4 ft cross section and one equivalent to 2.5 MW_e output having a 12.7 ft x 12.7 ft cross section. This concept is based on the judgment that both gravity-controlled downward flow of liquid feed and transverse pressure gradient controlled vapor flow can be independently established in such rectangular bundles to permit representation of a corresponding segment in any position of the full-scale cross section. The method of doing this is shown on the next chart.

TUBE BUNDLE SEGMENTAL TEST CONCEPT

VARIABLE LIQUID & VAPOR REFLUX

TUBE BUNDLE SEGMENTAL TEST CONCEPT

This diagram illustrates the proposed method of employing a square cross sectional tube-bundle segment combined with means for refluxing both vapor and liquid to simulate the behavior of the working fluid in any position of a full scale evaporator tube bundle. By this means the ratio of downward gravity-actuated liquid flow to pressure-actuated cross-flow of vapor can be studied experimentally to determine the influence on the local evaporative heat transfer conductance.

HEAT EXCHANGER DEVELOPMENT

F-50

HEAT EXCHANGER DEVELOPMENT SCHEDULE

The schedule shown, for the development of the heat exchangers, is predicated on the initiation of AR&T efforts at the time that the facility contract award is made. Heat transfer enhancements, working fluid dynamics, and heat exchanger geometry experiments can be undertaken utilizing available laboratory facilities. Producibility studies can be done at available vendor or contractor facilities. These experiments will be conducted intermittently throughout the program as new concepts are proposed.

Testing at the major component and land-based cycle plant sizes is dependent upon the availability of the facility. With the construction schedule as shown in the total program schedule, the 0.25 to 2.5 MW_e component test heat exchangers can be completed within the 30-month facility construction span. Similarly, the 3 to 6 MW_e land-based cycle plant heat exchangers can be completed well within the 48-month test facility construction span. The 6 to 10 MW_e heat exchangers for the sea-based cycle plant are the pacing items and installation should be complete for facility relocation to the test site by mid-1981.

It is assumed that the heat exchanger fabrication "learning curve" will permit design, fabrication, and assembly of the full-scale heat exchangers for the sea-based pilot plant within a 2-year period following the authorization to proceed.

REGENERATIVE GAS-PHASE (WET) TURBINE TEST

F-52

REGENERATIVE GAS-PHASE TURBINE TESTING

This schematic was presented at the contract kick-off meeting in January 1976. This concept permits large-scale turbine testing without the need for generating vapor from condensed liquid as would occur in a power cycle. The only heat exchanger required is a convective cooler for removing the heat introduced by the inefficiency of the turbine and load absorbing compressor.

AMMONIA TURBINE TEST BED SCHEMATIC

The implementation of the original concept previously shown includes features which permit testing more than one size turbine and also provides a method of controlling the quality of the vapor entering the turbine. A demister at the exit of the turbine is required to avoid erosion damage on the compressors. This thereby provides an excellent facility for the testing of candidate demister devices.

As shown in the test facility detail drawings, a separate circuit is available for testing smaller (1/16 scale) turbines.

LAND-BASED OTEC TURBINE TEST CAPABILITY

TURBINE CAPACITY (SIZE / MW_m)

	(1/16) 2.62	(1/4) 10.5	(FULL) 42
NH ₃ FLOW RATE (PPS)	180	710	2830
EXTERNAL POWER REQ'D. (MW _m / HP)	1.83 2455 HP	6.75 9,055	30.91 41,470
TURBINE / COMPRESSOR (RPM)	$\frac{4800}{4942}$	$\frac{2400}{2550}$	$\frac{1200}{2000}$

INLET NH₃ PRESSURE = 132 PSIA

EXIT NH₃ PRESSURE = 97.9 PSIA

LAND-BASED OTEC TURBINE TEST FACILITY CAPABILITY

This table summarizes the range of variables associated with operation of the 1/16 size and the 1/4 to full size turbine test beds. The values shown are based on a full scale power module output of 64 MW_e net and the final facility requirements will be adjusted as required by final power plant size selection.

Related rotating machinery experience indicates that full-scale performance can be reliably predicted from test data obtained from sub-scale models (1/4 scale). The additional expense for the full scale test capability may be justified by utilizing the facility for final acceptance testing of prototype and production hardware.

AMMONIA TURBINE TEST PRESSURE-ENTHALPY DIAGRAM

F-58

AMMONIA TURBINE TEST P-H DIAGRAM

This vapor phase cycle for regenerative turbine testing is illustrated by the corresponding small loop on the pressure-enthalpy grid. Since there is only one fluid involved in this process, the energy balance required for steady state requires only heat removal between the compressor discharge and turbine inlet. Control of wetness by means of the demister and reinjection of atomized liquid is, in effect, a small by-pass around the compressor. This detail is not depicted on the cycle diagram.

AMMONIA TURBINE DEVELOPMENT

F-60

AMMONIA TURBINE DEVELOPMENT SCHEDULE

Although considerable data are available on the scaling and parametric performance of power turbines, some effort is required to determine the effect of utilizing ammonia vapor as the working medium. The test requirements for the initial AR&T efforts will be established by mid-1977 and a vendor selected by the last quarter of 1977. The vendor will construct a test apparatus or modify an existing facility in order to undertake small scale development testing by the first quarter of 1978.

Development, fabrication, and delivery of the cycle plant turbine should be consistent with the component test facility construction schedule. The amount of testing, with the cycle-plant-sized turbine, is dependent upon the selection of a land-based or sea-based cycle plant. Delivery to the latter is required in the first quarter of 1981, while the former requires delivery by the last quarter of 1981.

Development, fabrication, and delivery of the full-scale turbine can follow a more relaxed schedule, since delivery to the sea-based pilot plant is not required until the last quarter of 1983. Delivery prior to the last quarter of 1982 would permit at least 1 year of testing prior to delivery to the pilot plant.

As with the other development schedules, this one is based on adherence to the overall OTEC program schedule shown previously.

COMPONENT LIST FOR TESTING AT VENDOR FACILITIES

COMPONENT	PROBLEM	PROJECTED GEOMETRIC SCALE FACTOR	CONFIDENCE LEVEL
PUMP, AMMONIA REFLUX	NPSH	1/4 / FULL	0.96 / 0.99
PUMP, AMMONIA FEED	NPSH	1/4 / FULL	0.96 / 0.99
AMMONIA CLEANUP SYSTEM	EFFECTIVENESS	1/10	0.95
COLD WATER PIPE JOINT	STRUCTURAL	1/20	0.95
MOORING LINE LINK	STRUCTURAL	1/20	0.95
TURBINE BEARINGS, SEALS, VANES	LIFE, RELIABILITY	FULL	0.99
PUMP BEARINGS, SEALS, GEAR BOX	LIFE, RELIABILITY	FULL	0.99

COMPONENT LIST FOR TESTING AT VENDOR FACILITIES

These components or subsystems will probably be furnished by subcontractors as complete assemblies, the performance of which will be the responsibility of each vendor as delineated in applicable specifications. The cost of development and demonstration will be a part of each contract and will include the necessary testing in a vendor-owned or vendor-leased facility. The testing requirements will be established jointly by the prime contractor and vendor and final acceptance tests will be witnessed by purchaser representatives.

Specific aspects which will require either development or demonstration testing of major components are listed, as well as the associated size or scale of the test article with a corresponding subjective level of confidence of achieving the initially predicted performance.

COMPONENT LIST FOR HYDRODYNAMIC TESTING

COMPONENT	PROBLEM	GEOMETRIC SCALE FACTOR	FACILITY	CONFIDENCE LEVEL
PLATFORM	DYNAMICS	1/100	LMSC, NSRDC, OTC	0.90
WARM WATER CIRCUIT	ΔP , PROFILES	1/50	HYDRONAUTICS, LMSC, NSRDC, OTC	0.90
COLD WATER CIRCUIT	ΔP , PROFILES	1/100	HYDRONAUTICS, LMSC, NSRDC, OTC	0.90
COLD WATER PIPE	DRAW, OSCILLATIONS	1/100	LMSC, OTC, NSRDC	0.90
MOORING LINE	DRAW, OSCILLATION	1/100	LMSC, OTC, NSRDC	0.90
ANCHOR	RESISTANCE SITE DEPENDENT	SITE DEPENDENT	NCEL PORT HUENEME	SITE DEPENDENT

COMPONENT LIST FOR HYDRODYNAMIC TESTING

The hydrodynamic testing listed can be accomplished in existing facilities with little or no modifications. While the scale factors are relatively small, the physical sizes of the models result in acceptable Reynolds numbers for flow simulation.

The dynamic response characteristics of the platform can be evaluated in a facility which incorporates a well, a wave-making device, and a suitable support system. The well facility can also be used for evaluating the sea water flow paths. A larger model can be utilized for the warm water circuit, since one quadrant is satisfactory while cold water circuit testing requires the complete plenum with multiple flow paths to the cold sea water pumps.

Cold water pipe, mooring line, and anchor tests can be accomplished in a hydraulics facility capable of simulating currents as well as generating waves.

Typical facilities are available at Lockheed Missiles & Space Company (LMSC) , Naval Ship Research Development Center (NSRDC), Offshore Technology Corporation (OTC) , Hydronautics, and the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme.

As in the previous slides, the confidence levels shown represent an engineering assessment of the probability of attaining the full scale performance based on model test data.

COMPONENT TEST - PRELIMINARY CONCLUSIONS

- LARGE SIZE HEAT EXCHANGERS, $> 1/5$ SCALE TURBINES AND SEAWATER PUMPS REQUIRE NEW TEST FACILITIES
- SUBSYSTEM COMPONENTS, SUCH AS AMMONIA CONDENSATE AND REFLUX PUMPS AND VARIOUS STRUCTURAL AND RELIABILITY TESTS CAN BE ACCOMPLISHED IN VENDORS FACILITIES
- HYDRODYNAMIC TESTING CAN BE ACCOMPLISHED IN AVAILABLE FACILITIES

COMPONENT LIST FOR HYDRODYNAMIC TESTING

The hydrodynamic testing listed can be accomplished in existing facilities with little or no modifications. While the scale factors are relatively small, the physical sizes of the models result in acceptable Reynolds numbers for flow simulation.

The dynamic response characteristics of the platform can be evaluated in a facility which incorporates a well, a wave-making device, and a suitable support system. The well facility can also be used for evaluating the sea water flow paths. A larger model can be utilized for the warm water circuit, since one quadrant is satisfactory while cold water circuit testing requires the complete plenum with multiple flow paths to the cold sea water pumps.

Cold water pipe, mooring line, and anchor tests can be accomplished in a hydraulics facility capable of simulating currents as well as generating waves.

Typical facilities are available at Lockheed Missiles & Space Company (LMSC) , Naval Ship Research Development Center (NSRDC), Offshore Technology Corporation (OTC) , Hydronautics, and the Naval Civil Engineering Laboratory (NCEL) at Port Hueneme.

As in the previous slides, the confidence levels shown represent an engineering assessment of the probability of attaining the full scale performance based on model test data.

TESTING I - TEST BEDS

PRESENTED BY
GERALD G. JOHNSON

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING I – TEST BEDS

LBTF heat exchanger test bed schematic
Evaporator test pressure-enthalpy diagram
Condenser test pressure-enthalpy diagram
LBTF heat exchanger test bed layout
Alternate layout for vertical heat exchanger
LBTF 2.5 MW heat exchanger test bed layout
Alternate layout for 2.5 MW vertical heat exchanger
Costs and schedules for 0.25 heat exchanger test bed
LBTF ammonia turbine test bed schematic
Ammonia turbine test pressure-enthalpy diagram
LBTF ammonia turbine test bed layout
Cost and schedule for ammonia turbine test bed
Seawater hydrodynamics test bed layout
Cost and schedule for seawater hydrodynamics test bed
Sea-based pump test bed layout
Pump test bed strongback assembly

LBTf HEAT EXCHANGER TEST BED SCHEMATIC

BTF HEAT EXCHANGER TEST BED SCHEMATIC

This schematic shows the interrelationships between the various fluid flow circuits in the heat exchanger test bed configured to test an 0.25 MW evaporator. The water flows in a closed loop from the circulating water pumps through the evaporator, through the condenser, and back to the pump inlet. Provisions are included for draining a small portion of the circulating water and replacing it with 60°F makeup water in order to compensate for the small temperature increase induced by the circulating water pump. An additional, and separate, water flow is provided to the ammonia subcooling heat exchanger. Water flow conditions are as follows:

<u>Station</u>	<u>Flow Rate (gal/min)</u>	<u>Water Temperature (°F)</u>
W1	26,375	79.75
W2	26,375	76.54
W3	26,375	79.70
W4	1,653	60.

The closed ammonia cycle circulates 1,356 lb/min of ammonia through the evaporator and condenser in order to extract heat from water in the evaporator and add heat to the water in the condenser.. The heat transfer performance requirements for the evaporator and condenser are:

Evaporator H1 , 42.37×10^6 Btu/hr, 6.317°F LMTD
Condenser H2 , 41.71×10^6 Btu/hr, 6.554°F LMTD

The ammonia vapor flowing from the evaporator outlet to the condenser inlet is heated by compression in a two-stage centrifugal compressor. Liquid ammonia from the condenser flows through a water cooled heat exchanger then through a mechanical refrigeration subcooler to reduce the ammonia temperature to the appropriate level for entry to the evaporator. State point conditions for the ammonia cycle are as follows:

<u>Station</u>	<u>Temperature (°F)</u>	<u>Pressure (psia)</u>	<u>Enthalpy (Btu/lb)</u>
A*	54.55	133.46	103.50
B*	71.37	131.92	624.25
C	115	183.00	650.22
D	111	167.07	650.22
E	84.80	165.86	137.56
F	67	164.86	117.22
G	55	164.36	103.50

* Baseline Conditions

EVAPORATOR TEST PRESSURE-ENTHALPY DIAGRAM

EVAPORATOR TEST PRESSURE-ENTHALPY DIAGRAM

This diagram shows the ammonia cycle state points for the baseline evaporator test. State point A at the entry to the evaporator and state point B at the entry to the compressor are the controlled conditions representing baseline evaporator operation. The compression process is represented by the line connecting points B and C. Adiabatic throttling reduces the pressure to point D at the entry to the condenser. Heat transfer in the condenser to point E reduces the enthalpy of the ammonia. Additional heat transfer to water (process E to F) and to a mechanical refrigeration subcooler (process F to G) reduces the enthalpy to the point G where throttling across a regulating valve closes the cycle back to point A.

CONDENSER TEST PRESSURE-ENTHALPY DIAGRAM

CONDENSER TEST PRESSURE-ENTHALPY DIAGRAM

This diagram shows the ammonia cycle state points for the baseline condenser test. State point D at the entry to the condenser and state point E at the exit of the condenser are the controlled conditions representing baseline condenser operation. Ammonia from the condenser is cooled to point F by heat transfer to a mechanical refrigeration subcooler. Expansion through the regulating valve to point A reduces the liquid ammonia pressure for subsequent evaporation along the process line points A to B. The ammonia vapor is then compressed along the process line from points B to C and desuperheated by liquid ammonia spraying to close the cycle at point D.

LBTF HEAT EXCHANGER TEST BED LAYOUT

This drawing shows the layout of the heat exchanger test bed. The building housing all test equipment is 159 ft long by 109 ft wide by 60 ft high. This building incorporates the water and ammonia cycle equipment along with servicing floor space, instrumentation and control room, and a 100 ton capacity bridge crane.

ALTERNATE LAYOUT FOR VERTICAL HEAT EXCHANGER

G-12

ALTERNATE LAYOUT FOR VERTICAL HEAT EXCHANGER

This layout shows the effects on the heat exchanger test facility of installing the vertical Applied Physics Laboratory (APL) condenser and evaporator designs. These heat exchangers protrude through the existing roof structure with a maximum water level elevation of 80 feet above grade. An additional booster pump is required to pump the circulating water up to the water level of four feet above the top of the heat exchangers. Liquid ammonia sumps are provided on both the condenser and evaporator.

COSTS AND SCHEDULE FOR 0.25 HEAT EXCHANGER TEST BED

CONSTRUCTION COST

CONSTRUCTION SCHEDULE

COST AND SCHEDULE FOR 0.25 MW HEAT EXCHANGER TEST BED

The bar graph shows the construction cost of the LBTF heat exchanger test bed. The costs are divided into major categories as follows.

Mechanical: Purchase and installation of test bed mechanical equipment.

Electrical: Purchase and installation of electrical equipment and materials.

Piping and Instrumentation: Purchase and installation of process piping and instrumentation.

Civil/Structural: Construction materials and labor for the test bed building and internal civil and structural features.

Engineering Services: Engineering, home office cost and fee.

Allowance for Uncertainty: Allowance for the uncertainties that exist in quantity, pricing and productivity within the scope of the conceptual design.

The construction costs are dominated by the cost of the building required to house the heat exchanger test arrangement.

The schedule shows the major phases of the heat exchanger test bed design and construction as a part of the overall LBTF construction. The test bed can be completed approximately 33 months after the initiation of the LBTF engineering. The building construction and placement and testing of equipment and materials in it are the critical items.

LBTF 2.5 MW HEAT EXCHANGER TEST BED LAYOUT

This drawing shows the layout of the 2.5 MW heat exchanger test bed. It is ten times larger in capacity than the one presented previously. The water flow capacity of 263,750 gal/min requires ten feet diameter piping and the use of three parallel 1,000 hp water circulating pumps. A corresponding increase of refrigeration capacity to 13,560 lb/min of ammonia can be accomplished with a single 9,000 hp compressor.

The building housing all test equipment is 254 ft long by 145 ft wide by 60 ft high. This building incorporates the water and ammonia cycle equipment along with servicing floor space, instrumentation and control room, and a 200 ton capacity bridge crane.

ALTERNATE LAYOUT FOR 2.5 MW VERTICAL HEAT EXCHANGER

ALTERNATE LAYOUT FOR 2.5 MW VERTICAL HEAT EXCHANGER

This layout shows the effects on the 2.5 MW heat exchanger test facility of installing the vertical Applied Physics Laboratory (APL) condenser and evaporator designs. These heat exchangers protrude through the existing roof structure with a maximum water elevation of 80 feet above grade. Three additional booster pumps are required to pump the circulating water up to the water level of four feet above the top of the heat exchangers. Liquid ammonia sumps are provided on both the condenser and evaporator.

COSTS AND SCHEDULE FOR 2.5 MW HEAT EXCHANGER TEST BED

CONSTRUCTION COST

CONSTRUCTION SCHEDULE

COST AND SCHEDULE FOR 2.5 MW HEAT EXCHANGER TEST BED

The bar graph shows the construction cost of the LBTF heat exchanger test bed. The costs are divided into major categories as defined in the 0.25 MW Heat Exchanger Test Bed Cost Discussion.

The construction costs are dominated by the cost of the building required to house the heat exchanger test arrangement.

The schedule shows the major phases of the heat exchanger test bed design and construction as a part of the overall LBTF construction. The test bed can be completed approximately 36 months after the initiation of the LBTF engineering. The critical scheduling items are the design, procurement, installation, and testing of the major mechanical equipment.

LBTf AMMONIA TURBINE TEST BED SCHEMATIC

G-22

LBTF AMMONIA TEST BED SCHEMATIC

The ammonia fluid flow circuit schematic for testing the full and 1/4-size turbines is shown. Either size of turbine can be installed on the left side of the turbine-motor-compressor drive train for testing. When the 1/4-size turbine is tested the outboard pair of 187,000 acfm compressors are uncoupled from the power train. For full size turbine testing, all compressors remain coupled. Ammonia vapor from the compressors is collected and cooled by heat transfer to water in the desuperheater. From the desuperheater the ammonia vapor flows into the turbine at state point conditions corresponding to the baseline plant. The ammonia expands through the test turbine and then passes through the demister to the compressor inlet manifold. Since power produced by the turbine is not sufficient to drive the compressors the difference is provided by the electric motor.

	Turbine	A lb/sec	B lb/sec	C Btu/hr	D lb/sec	E gpm	F MW
Full Size	42 MW	2832.3	2773.1	92.24×10^6	59.2	36,862	30.91
1/4 Size	10.5 MW	708.1	693.3	23.06×10^6	14.8	4,070	7.73

G-23

The test bed equipment and services were sized to accomodate turbines up to the capacity required in an interim baseline of March 1976. This interim baseline had a generator net output of approximately 42 MWe. The June 1976 baseline has a generator net output of 45 MWe, an increase of 6.7 percent over the turbine size stated above. Comparing the two baselines shows a decrease in the ammonia flow rate (column A reduces to 2724 lb/sec) and an increase in electric motor input. These changes were estimated to be within the cost/schedule procedure used and therefore no change was made to the test bed or its estimated cost.

A 1/16 performance scaled turbine test bed arrangement was established to assure capability of testing across the range of forecasted value.

AMMONIA TURBINE TEST PRESSURE-ENTHALPY DIAGRAM

G-24

AMMONIA TURBINE TEST PRESSURE-ENTHALPY DIAGRAM

This diagram shows the ammonia cycle state points for the baseline turbine tests. All of the turbines (full, 1/4 and 1/16 scale) operate on the same cycle shown by this diagram. Subsaturated ammonia vapor enters the test turbine at point N1 and expands to point N2 where it enters a moisture separator. The vapor from the separator, state point N3, is compressed to point N4 and cooled to point N5 by heat transfer to cooling water. The ammonia liquid from the moisture separator is pumped and sprayed into the ammonia gas stream to further cool it to state point N1, thereby closing the cycle.

LBTF AMMONIA TURBINE TEST BED LAYOUT

This drawing shows the layout of the turbine test bed. The building housing the rotating machinery is 195 ft long by 76 ft wide by 78 ft high. This building incorporates ammonia cycle equipment for testing full and 1/4-scale turbines plus a separate cycle for testing 1/16-scale turbines. Also incorporated into the building are an instrumentation and control room, and a 100 ton capacity bridge crane. Both horizontal and vertical turbines can be tested.

COST AND SCHEDULE FOR AMMONIA TURBINE TEST BED

CONSTRUCTION COST

CONSTRUCTION SCHEDULE

COST AND SCHEDULE FOR AMMONIA TURBINE TEST BED

The bar graph shows the construction cost of the turbine test bed divided into major categories as defined previously in the heat exchanger test bed cost discussion. The mechanical equipment, dominated by the ammonia compressors and drive motor, and the building construction cost are the major cost items.

The schedule shows that the turbine test bed can be completed 36 months after initiation of the LBTF engineering. The critical scheduling items are the design, procurement, installation and testing of the major mechanical equipment.

SEAWATER HYDRODYNAMICS TEST BED LAYOUT

G-30

SEA WATER HYDRODYNAMICS TEST BED LAYOUT

The sea water hydrodynamic test bed provides for flow testing of up to 1/50 scale models. This facility includes the pool and equipment necessary for supporting and servicing of test models. A bridge structure over the top of the pool is provided for mounting of test models and support of instrument and power cables. A vertical extended shaft submersible pump is provided for draining the pool and for use in circulating water through the models, if so desired. The building is 100 ft. long by 70 ft. wide by 50 ft high and includes a 20 ton bridge crane for handling of models and other test equipment.

COST AND SCHEDULE FOR SEAWATER HYDRODYNAMICS TEST BED

G-32

CONSTRUCTION COST

CONSTRUCTION SCHEDULE

COST AND SCHEDULE FOR SEAWATER HYDRODYNAMICS TEST BED

The bar graph shows the construction cost of the hydrodynamics test bed divided into categories as previously defined in the heat exchanger test bed discussion. The civil/structural cost of the test tank and building are the major cost items.

The schedule shows that the hydrodynamics test bed can be completed 27 months after initiation of the LBTF engineering effort. The critical scheduling items are construction of the tank and building following site preparation.

SEA-BASED PUMP TEST BED LAYOUT

This layout shows a representative pump test assembly. Since pump assemblies are to be tested with both a vertical and horizontal centerline orientation, the technique selected is to provide a tubular framework within which the inlet, transition sections, pump and tailpiece can be installed on the working deck of a test barge or other vessel. The entire test assembly can then be lowered into the sea and oriented for either horizontal flow testing or for vertical flow testing with the inlet bell-mouth up. This approach will minimize the number of diver hours required for tests and will permit test hardware and instrumentation installations to be accomplished in a dry environment.

The flow restriction device envisioned for this testing is a series of over-lapping slats at the exit of the tailpiece. These slats are linked so that they function like a venetian blind to restrict the opening evenly over the entire flow area rather than provide a large flow distorting central plug similar to that created with a butterfly valve. A thrust neutralizer is incorporated at the duct exit to minimize thrust input to the support vessel.

PUMP TEST BED STRONGBACK ASSEMBLY

G-36

PUMP TEST BED STRONGBACK ASSEMBLY

This drawing shows the conceptual technique for testing the pump in either a horizontal or vertical centerline orientation. The inlet end of the pump support structure is hinged to a strongback frame. Two cable attach points and two latch devices at the aft end of the pump support structure allow the structure to pivot down from the strongback for vertical centerline testing or remain latched to the strongback for horizontal centerline testing. Hydraulic driven winches on the strongback frame provide the lifting effort for the cables.

Four attach points on the top of the strongback frame will attach to the surface support vessel through an appropriate lifting mechanism. Although the support vessel is not selected at this time, this design anticipates a semi-rigid lifting mechanism similar to jack-up lifting legs presently used on many drilling rigs.

TESTING II

SYSTEMS TEST/SYSTEMS ANALYSIS

PRESENTED BY
CHARLES M. ROBIDART

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING II – SYSTEMS TEST/SYSTEMS ANALYSIS

Testing II definition

Testing II purpose/objectives

3 MWe cycle plant – titanium tubes

Cycle plant test requirements

Thermal resource evaluation

Once Through cooled power plants

Typical thermal resource capability

Thermal resource augmentation

Cycle plant water flow and design SRE requirements

Ratio of warm to cold water flow

Effect of warm water to cold water ΔT on net power

Land-based cycle plant design guidelines

Sea-based cycle plant design guidelines

TESTING II - DEFINITION

TESTING II SYSTEMS TESTS AND SYSTEMS ANALYSIS

- POWER CYCLE TESTS

 - CYCLE PLANT – LAND-BASED

 - SEA-BASED

- THERMAL RESOURCE EVALUATION

- TEST FACILITY SUPPORT

- DATA ACQUISITION SYSTEM

- TEST FACILITY COST/SCHEDULE INTEGRATION

TESTING II - DEFINITION

Testing II is in general terms the system tests and systems analysis. These functions are contained in Study Task A - Establishment of System Test Requirements; Study Task E - Establishment of Test Facilities Support Requirements; Study Task F - Systems Analysis; and Study Task G - Thermal Resource Evaluation.

The system tests are the power cycle tests called cycle plant which may be either land-based or sea-based. Included in the system tests are the contributing factors such as the baseline definition, the range of tests, cycle plant arrangements, energy self sufficiency, and ancillary equipment performance.

Thermal resource requirement for land-based cycle plants is of such magnitude that it is considered an important aspect of Testing II. The systems analysis activity include the definition of test facility support requirements and the data acquisition and control system; the integration of cycle plant(s) with other test beds, be they on-land or at-sea; and the coordinated set of test facility requirements, estimated costs, and conceptual schedules.

TESTING II-PURPOSE/OBJECTIVES

LAND-BASED AND SEA-BASED CYCLE PLANT

- DEFINE FACILITY REQUIREMENTS
- DEFINE CAPABILITY AND CONSTRAINTS
- ESTABLISH ESTIMATED COSTS AND CONCEPTUAL SCHEDULES

TEST FACILITY

- DEFINE SUPPORT REQUIREMENTS INCLUDING DATA ACQUISITION AND CONTROL SYSTEM
- INTEGRATE TEST ARRANGEMENTS AND FACILITY SUPPORT INTO TEST FACILITY REQUIREMENTS
- DEFINE CAPABILITY AND CONSTRAINTS
- ESTABLISH ESTIMATED COSTS AND CONCEPTUAL SCHEDULES

TESTING II PURPOSE/OBJECTIVES

The purpose/objectives of Testing II are to derive for the cycle plant(s) the test facility support aspects and for the test facility their requirements, their estimated costs, their conceptual schedules, and their definition of constraints or risks. The cycle plant(s) requirements include performance capability in terms of size, i.e. megawattage rating. The cycle plant(s) together with AR&T and component test requirements and test facility support requirements will form the test facility requirements. For each component test bed, each cycle plant and the test facility support items an estimated cost was established. This cost includes capital expenditures for test bed construction and hardware, and the test facility support or ancillary equipment. Further, the costs include capitalized operating expenses of personnel, power, overhead, and an allocation for general and administrative charges.

H-7

The conceptual schedule includes test bed construction time spans, OTEC equipment and test bed equipment procurement time spans, the mobilization of OTEC equipment into the test bed, and the time span for checkout of all equipment in the test bed.

The diagram illustrates a steam Rankine cycle with reheat and regeneration. The cycle components and their connections are as follows:

- EVAPORATOR:** Receives feedwater from the condenser pump (point 7) and the reflux pump (point III). It is heated by warm water (point A) and steam from the turbine (point I). The saturated vapor (point 9) goes to the demister, and the saturated liquid (point II) goes to the reflux pump.
- DEMISTER:** Removes liquid droplets from the steam. It receives steam from the evaporator (point 9) and returns liquid to the evaporator (point I). The dry steam (point 1) enters the turbine.
- TURBINE:** Expands the steam from point 1 to point 2. A portion of the steam is extracted at point 3 and sent to the demister. The main flow continues to point 4.
- CONDENSER:** Condenses the steam from point 4 using cold water (point C). The condensate (point 5) is pumped back to the evaporator by the condensate pump (point 6).
- REFLUX PUMP:** Pumps the saturated liquid from the evaporator (point II) back to the evaporator inlet (point III).
- WARM WATER:** A separate heating source that provides heat to the evaporator (point A).

The cycle is labeled with points 1 through 9 and Roman numerals I, II, III, and D. The flow is clockwise, starting from the condenser and returning to the evaporator.

CYCLE DIAGRAM - CYCLE PLANT

To assist in defining the cycle plant state points and pertinent characteristics, eight computer runs were made using as a base the June 1976 Baseline. These eight runs were divided into two groups, heat exchanger tubes of titanium or aluminum, at net power output levels of 1, 3, 6, and 9 MW. The "net power output" is the generator gross less the power for the cycle plant auxiliaries consisting of the sea water pumps, the condensate pump, and the reflux pump.

Two guidelines were established for these eight computer runs. The first guideline was to increase the tube wall thickness to withstand the working fluid shell pressure with only atmospheric pressure on the tube side. This resulted in an 0.058-in. wall for titanium and an 0.065-in. wall for aluminum. The second guideline was to approximate the same total L/D ratio for the evaporator plus condenser tubes as the baseline, letting the number of tubes (and consequently the shell diameter) vary to provide the required tube surface area.

CYCLE PLANT TEST REQUIREMENTS

- CONDUCT SCALED OPERATIONAL POWER CYCLE SYSTEM TESTS
- DETERMINE COMPONENT PERFORMANCE AND COMPONENT INTERACTIONS
IN POWER CYCLE CONFIGURATION
- ESTABLISH OFF-DESIGN POWER CYCLE PERFORMANCE CAPABILITY
- VERIFY ANCILLARY POWER CYCLE EQUIPMENT PERFORMANCE AND
EFFECTS ON POWER CYCLE PERFORMANCE
- VERIFY POWER CYCLE OPERATIONAL AND MAINTENANCE PROCEDURES

CYCLE PLANT TEST REQUIREMENTS

The cycle plant test requirements, together with the cycle plant systems (main components and functional and auxiliary systems) and the parameters contained in the cycle diagram, form the basis for deriving and defining the cycle plant test arrangements.

The five cycle plant test requirements are to conduct scaled operational power cycle system tests which provide means of verifying the OTEC concept and to determine how accurately the analytical methods can predict system performance. The cycle plant test also provides the first opportunity to test the main components in a system configuration. The system configuration provides component performance definition and determination of component interactions.

As the power cycle will be designed for a defined set of conditions, the cycle plant provides the capability of determining and evaluating performance to various off-design points.

An important feature of the cycle plant is to test key ancillary or auxiliary systems to the power cycle such as control system sensitivity, selected fouling countermeasures, ammonia clean-up, etc. Finally, various operational and maintenance procedures can be demonstrated and verified prior to their usage on the prototype or demonstration plants.

THERMAL RESOURCE EVALUATION

- DEFINE LAND-BASED THERMAL RESOURCES LIMITATIONS
- CORRELATE THERMAL RESOURCES WITH LAND BASED CYCLE PLANT SIZE

THERMAL RESOURCE EVALUATION

The purpose of conducting the evaluation of land-based power plant thermal resources was to determine the practical limitations to the performance size of a land-based cycle plant. The thermal resources task did not, nor was it intended to, yield sufficient data regarding site conditions and diurnal and seasonal temperature differential variations to arrive at recommendations for site selection.

A brief survey of existing power plants was conducted to define their available thermal resource, i.e., the power plants cooling water flow rate and its outlet temperature compared to cooling water inlet temperature. These data were then correlated with the thermal resources required by various performance sizes land-based cycle plants. This correlation defined practical limits to the land-based cycle plants.

Typical of the survey was 43 letters soliciting information on potential sites with thermal resource capability of supporting a cycle plant 19 responses were received. Of these, only 2 appeared to have the necessary qualifications.

ONCE-THROUGH COOLED POWER PLANTS

OWNER	PLANT	COOLING WATER RATED CONDITIONS	
		ΔT (°F)	FLOW (GPM)
ASSOCIATED ELECTRIC COOPERATIVE, INC.	NEW MADRID	28°-W	330,000
CAROLINA POWER & LIGHT	ROXBORO	32°-W, 32°-S	404,000
CONSUMERS POWER COMPANY	PALISADES	25°-W, 17°-S	404,000
CONSUMERS POWER COMPANY	WEADOCK	29°-W	408,000
DUKE POWER COMPANY	ALLEN	29°-W, 21°-S	452,000
ENERGY ELECTRIC, INC.	JOPPA	33°-W, 24°-S	339,000
CONNECTICUT LIGHT & POWER CO.	MONTVILLE	30°-W, 22°-S	273,000
DAYTON POWER AND LIGHT CO.	STUART	30°-W, 27°-S	684,000
GULF POWER COMPANY	CRIST	29°-W, 24°-S	303,000
NEW ORLEANS PUBLIC SERVICE, INC.	MICHOUD	27°-W, 29°-S	312,000
OHIO EDISON COMPANY	SAMMIS	32°-W, 27°-S	962,000
PENNSYLVANIA POWER & LIGHT	BRUNNER ISLAND	46°-W, 25°-S	485,000
SAN DIEGO GAS & ELECTRIC	SOUTH BAY	28°-W, 23°-S	367,000
VIRGINIA ELECTRIC POWER CO.	CHESTERFIELD	34°-W, 18°-S	632,000
WASHINGTON PUBLIC POWER SUPPLY SYSTEM	HANFORD	50°-W, 33°-S	375,000

W - WINTER

S - SUMMER

ONCE-THROUGH COOLED POWER PLANTS

A brief survey of possible thermal resources for an OTEC cycle plant was made by discussions with Bechtel operating division personnel and a review of Environmental Protection Agency (EPA) and Federal Power Commission (FPC) reports. Industrial and refinery processes appeared to have water flows considerably less than that required for an OTEC cycle plant. Once-through cooled power plants were investigated; mainly by review of the FPC Summary Report, Steam-Electric Plant Air and Water Quality Control Data for the year ended 1972, published in May 1975. A list of those plants meeting the flow requirements (300,000 gpm minimum) and approaching the desired thermal gradient (30-35°F) is shown in the slide. Roxboro, Brunner Island and Hanford appeared to be the most desirable candidates and were investigated further.

The Roxboro plant was found to discharge into a cooling pond and was eliminated from further consideration. The Hanford plant operates intermittently, from 20-52 days at a time and is shut down for 3 months during the summer. The Brunner Island plant site experiences flooding almost every spring and any additional test area would have to be dike protected and/or filled.

TYPICAL THERMAL RESOURCE CAPABILITY

COOLING TOWER

- A CENTRALIA 1 & 2
- B VOGTLE/JIM BRIDGER 1, 2 & 3
- C LIMERICK 1 & 2/WATTS BAR 1 & 2
- D BROWNS FERRY 1, 2 & 3

NUCLEAR

- E 9 MILE POINT - NEW YORK
- F HANFORD - WASH.

FOSSIL

- G SOUTH BAY - SAN DIEGO
- H ROXBORO - CAROLINA P & L
- I STUART - DAYTON P & L
- J SAMMIS - OHIO EDISON
- K MOSS LANDING - FAC

TYPICAL THERMAL RESOURCE CAPABILITY

The thermal resource required by a cycle plant can be expressed as the warm water mass flow rate times the temperature differential of the warm water minus the cold water. This product of mass flow times temperature differential is analogous to a heat source expressed in Btu/sec. The plot shows a diagonal line which correlates the cycle plant "net" power in megawatts to the thermal resource. The "net" power is the power output shown on the cycle plant cycle diagrams shown earlier – the "net" power is the cycle plant generator output less the power used by the water pumps, condensate pumps, and reflux pumps.

Selected power plants are noted by vertical lines with the alpha notation corresponding to the tabulated list. Seasonal variations are noted by S-summer and W-winter. The thermal resource available at the power plant is determined by projecting the vertical line to the abscissa. At the intersection of the vertical line with the diagonal the cycle plant size can be defined by going horizontally to the ordinate.

The list of typical plants is actually very selective as very few power plants have the thermal resource requirement to support a large land-based cycle plant; therefore, for practical limitations a 3 MW was selected as being a practical limit.

THERMAL RESOURCE AUGMENTATION

H-18

AUGMENTING DEVICE

ELECTRICAL

FUEL OIL

HEAT PUMP

RELATIONSHIP/PERFORMANCE

948 BTU/SEC/MW_e AT 100%

18000 BTU/LB AT 100%, 10 BBL/HR/MW_e

ALL GENERATOR OUTPUT/COP = 10

AT °F

0.08

1.0

1

THERMAL RESOURCE AUGMENTATION

Based on potential limited thermal resources for operating the cycle plant, several methods of increasing the water temperature differential between the warm water supply and the cold water supply were investigated.

The diagram indicates the approach used. The heat source/sink increases the temperature level in the warm water supply and/or reduces the temperature level in the cold water supply to the cycle plant. The electrical augmentation device adds heat to the warm water by use of heaters immersed in the water duct. The cycle plant generator can supply the electricity (all remaining after cycle plant pumps or equipment usage). The relationship/performance indicates using 1 MW at 100% effectiveness gives only 0.08°F for a 1 MW cycle plant.

H-19

A fuel oil heating system, operating with 18,000 Btu/lb LHV at 100% effectiveness, requires 10 barrels of oil per hour per MW of cycle plant output to give 1°F increase in warm water temperature (a 3 MW cycle plant, 10°F water temperature increase requires 300 barrels per hour).

A heat pump whose motor uses the cycle plant generator output (less cycle plant pumps and equipment operating at a coefficient of performance (COP) of 10 can increase the temperature differential by 1.2°F. The COP is achieved by condensing the refrigerant using the warm water (increases warm water temperature) and expanding the refrigerant using the cold water (reduces cold water temperature).

Summarizing the above approaches thermal resource augmentation is not warranted for reasons of lack of ΔT increase and cost.

CYCLE PLANT WATER FLOW & DESIGN SIZE REQUIREMENTS

CYCLE PLANT WATER FLOW & DESIGN SIZE REQUIREMENTS

The nomogram shown can be used to estimate the total water flow rate required for specified net power output with various water temperature differences and pumping head losses. The data are not exact since the calculations assumed constant efficiency over the range shown. The actual water flow rate values will be higher at temperature differences less than the baseline value and vice versa.

Usage of the nomogram is best explained by the three examples:

(A) Determine the flow rate for a 12 MW_e net cycle plant operating at the baseline condition with no additional head loss. Answer is 2.27×10^6 GPM.

(E) Determine the flow rate and the design size required to provide 6 MW_e net with 36° F temperature difference and 3 ft additional pumping head. The total flow rate required is 1.67×10^6 GPM and the plant size is such that it would provide 8.8 MW_e net at the baseline operating condition.

(C) Determine the flow rate required and the net output of a 15 MW_e net design plant operating at a 40° F temperature differential with 1 ft additional pumping head. The total flow rate is 2.83×10^6 GPM and the net output is 16.2 MW_e.

RATIO OF WARM TO COLD WATER FLOW

RATIO OF WARM TO COLD WATER FLOW

The curve shown is used with the nomogram on the previous page to estimate the individual values of the warm and cold water flow rates. Computations made over a range of actual temperatures as well as temperature differences indicate that the latter has a primary effect on the flow ratio while actual temperatures have a secondary effect.

Usage of the curve is best explained by the examples of the previous page:

- (A) At the baseline temperature difference of 38° F, the ratio of 1.076. Dividing the total flow of 2.27×10^6 GPM by (1 + Ratio) gives a cold water flow of 1,093,000 GPM and a warm water flow of 1,177,000 GPM.
- (B) At the 36° F temperature difference, the ratio of 1.105. With a total flow rate of 1.67×10^6 GPM, the cold water flow rate is 793,000 GPM and the warm water flow rate is 877,000 GPM.
- (C) At the 40° F temperature difference, the ratio of 1.054. With the total flow rate of 2.83×10^6 GPM, the cold water flow rate is 1,378,000 GPM and the warm water flow rate is 1,452,000 GPM.

EFFECT OF WARM WATER TO COLD WATER ΔT ON NET POWER

WATER FLOW ADJUSTED TO MAINTAIN CONSTANT GROSS POWER

BASELINE

6 MW_e NET

T_W = 79.75°F

T_C = 41.77°F

T_{AV} MAINTAINED AT 60.76°F. CYCLE

PLANT WITH 0.058-IN. WALL Ti TUBES

EFFECT OF WARM WATER TO COLD WATER ΔT ON NET POWER

Computations were made to determine the effect of water temperature difference on net power, assuming that efficiencies remain constant over the ΔT range of interest and that the water flow rates are adjusted to maintain constant total heat transfer. The constant heat transfer rates and efficiencies result in constant gross power and the net power is determined by correcting for the water flow pumping power requirements.

As with the previous figures, this should be used only to estimate the performance characteristics as a function of water ΔT . It is apparent, however, that the baseline condition for the design of the heat exchangers is a primary factor in determining the performance at a given water temperature difference.

LAND-BASED CYCLE PLANT DESIGN GUIDELINES

		<u>ORIGINAL</u>		<u>FINAL-LAND BASED</u>
PLANT OUTPUT (MW)	3	6	9	3
WATER ΔT ($^{\circ}F$)	>30	>30	>30	34
WATER FLOW RATES (WARM PLUS COLD)				
CFS	1200	2400	3000	1500
GPM ($\times 10^3$)	540	1080	1620	670

WATER QUALITY

TYPICAL OF CIRCULATING WATER USED IN
STEAM-GENERATING PLANTS

ACCEPT VARIOUS COMPONENT CONFIGURATIONS

0 - 15 $^{\circ}$ HEAT EXCHANGER ANGLE ORIENTATION

CAPABILITY OF TESTING KEY AUXILIARY SYSTEMS

10-YR LIFE TEST BED

MINIMIZE CONSTRUCTION / OPERATING COSTS

LAND-BASED CYCLE PLANT DESIGN GUIDELINES

The key land-based cycle plant design guidelines are shown. The original values of 3, 6, and 9 MW output were selected early in the study as a reasonable scaled size prior to completion of either the scaling study or the thermal resource evaluation. The final land-based performance size was selected by the practical limitation of land thermal resources. The 34°F final value is a selected design point and with the water flow rate assures a test bed capability of operating the cycle plant at an off-design point, which is above its rated capability.

The acceptance of various component configurations allows testing of external configuration changes as well as internal variations. However, interfacing hardware for all component configurations was not defined. The 0-15° heat exchanger angle orientation mainly applies to horizontal shell and tube configuration although it is applicable to other configurations. The 10-year test bed life which applies to test bed components more than the concrete structure is consistent with overall test plans.

SEA-BASED CYCLE PLANT DESIGN GUIDELINES

PLANT OUTPUT (MW)	3	6	9
WATER ΔT ($^{\circ}F$)	> 30	> 30	> 30
WATER FLOW RATES (WARM PLUS COLD)			
CFS	1260	2520	3675
GPM ($\times 10^3$)	566	1131	1650
COLD WATER PIPE LENGTH (FT)	1200	1200	1200

ACCEPT VARIOUS COMPONENT CONFIGURATIONS

0 - 15° HEAT EXCHANGER ANGLE ORIENTATION

CAPABILITY OF TESTING KEY AUXILIARY SYSTEMS

CAPABILITY OF OPERATION BELOW SEAWATER LEVEL

10-YR LIFE TEST BED

OTEC EQUIPMENT ARRANGEMENT INDEPENDENT OF SEA-TEST PLATFORM

SEA-BASED CYCLE PLANT DESIGN GUIDELINES

The key sea-based cycle plant design guidelines were given in order to arrive at a physical size cycle plant layout. As in the land-based cycle plant, the three sizes of 3, 6, and 9 MW were selected as reasonable scaled sizes to allow direct comparison to the land-based cycle plant. The specific size has not been selected as of this date.

The 1200-ft cold water pipe provides a temperature differential of about 30° F. The acceptance of various components and configurations allows testing external configuration changes as well as internal variations. However, as interfacing hardware for all component configurations was not defined, and based on the platform selected, there may be problems in fitting all components together in the platform, i.e., a size or space restriction. The 0-15° heat exchanger angle orientation mainly applies to horizontal shell and tube configuration although it is applicable to other configurations. The capability to operate below sea water surface level allows depth orientation for platform accommodation as well as performance variation of sea water pumps.

The 10-year testbed life applies to both testbed components as well as the platform. This period is consistent with overall test plans..

TESTING II

LAND BASED CYCLE PLANT

PRESENTED BY
GERALD G. JOHNSON

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING II - LAND BASED CYCLE PLANT

Manufacturers contacted

Bulb-type pumps

Heat exchangers

Turbine generator

Bathtub configuration

Alternate earthwall construction

Grade configuration

Alternate cantilever wall construction

LBTF cycle plant configuration cost comparison

LBTF cycle plant cost-effect of scale

Tradeoff considerations

Selected configuration

Vertical downflow APL heat exchanger arrangement

Vertical downflow LMSC panel heat exchanger arrangement

Piping and instrumentation diagram

Auxiliary systems

Cost for 3 MW cycle plant

3 MW cycle plant construction schedule

MANUFACTURERS CONTACTED

HEAT EXCHANGERS

YUBA

SOUTHWEST ENGINEERING

WYATT INDUSTRIES

INDUSTRIAL FABRICATORS

TURBINES

HITACHI

IHI

AIRCO

ROTOFLOW

PUMPS

MITSUBISHI

ALLIS CHALMERS

LEFFEL

MANUFACTURERS CONTACTED

During development of the cycle plant concepts, manufacturers were contacted for technical and cost information regarding the major equipment items. Manufacturers are listed in the slide for the heat exchangers, turbines and pumps in the order corresponding to the degree of cooperation received. All manufacturers listed were helpful and provided valuable information regarding equipment performance and availability. An approximately equal number of manufacturers declined to provide information at this time.

BULB-TYPE PUMPS

BULB-TYPE PUMPS

This shows a cross-section from a Mitsubishi drawing of a cycle plant pump. This pump overcomes the friction drop in the heat exchanger and associated piping only and is supplemented by the intake structure pumps. Although the drawing shows the pump casing embedded in concrete, the cycle plant pump casing would actually be structurally supported in the cycle plant test bed. Typical overall dimensions (in feet) are as follows:

	<u>3 MWe</u>	<u>6 MWe</u>	<u>9 MWe</u>
D-2	8.2	11.5	13.8
D-4	16.1	18.7	22.5
D-6	15.4	19.8	24.1
L-10	32.8	41.3	50.4

Specific speed for this pump was recommended to be 21,200 by Mitsubishi. Efficiencies for the pump, motor and gear are estimated to be 85.5%, 94% and 98% respectively for an overall efficiency of 78.8%. The pump speed will depend on the final cycle plant flowrate and head but will be in the vicinity of 100 rpm.

Scale factor studies indicate that the inclusion of this pump in the cycle plant is optional since the pump can be model tested by the pump manufacturer. The friction drop in the heat exchanger and associated piping can be overcome by adding some additional capacity to the intake structure pumps. Operation of the pump in the cycle plant would simulate OTEC plant operating conditions with the above pumps being lower capacity than the full scale OTEC pumps.

HEAT EXCHANGERS

HEAT EXCHANGERS

The LMSC heat exchanger design was sent to manufacturers for their comments, a recommended mechanical design and an estimated cost. The slide shows one manufacturer's (Yuba) recommended method of construction for the cycle plant heat exchangers. For this design, each heat exchanger would be made up of a number of tube bundles inserted and bolted to a common shell cylinder. The slide shows a design with four bundles per shell as required for the 3 MWe net cycle plant heat exchangers. For the 6 MWe and 9 MWe net cycle plant heat exchangers, Yuba recommended nine and sixteen bundles per shell respectively. The number of bundles per shell was established in consideration of approximately 100" as a maximum bundle width. Yuba proposes that the bundles be fabricated by the heat exchanger manufacturer and shipped to the site. The shell would be fabricated on site and the complete unit would then be assembled in place.

Although not shown in the slide, the evaporator would be provided with a spray dome and distribution system, a sump and an exit vapor dome with built-in demisters. The condenser would be provided with a turbine exhaust dome and a sump.

Costing information was based on the LMSC specified dimensions and heat transfer areas.

TURBINE GENERATOR

I-10

OUTLINE DIMENSIONS (FEET)

SYMBOL	NET POWER OUTPUT		
	3 MW	6 MW	9 MW
A	10.2	11.2	11.8
B	12.5	13.1	13.8
C	2.0	2.0	2.0
D	8.2	9.2	9.8
E	7.9	8.3	8.7
F	7.1	7.4	7.5
G	1.9	2.0	2.1
H	1.0	1.0	1.2
J	5.0	5.3	5.4

TURBINE GENERATOR

Responses were received from several manufacturers regarding the cycle plant turbine generator as follows:

Airco - horizontal, axial, single flow, single stage, reaction type.

Rotoflow - horizontal, radial inflow, single flow, single stage, reaction type.

IHI - vertical, axial, single flow, single stage, impulse type.

Hitachi - vertical, axial, single flow, single stage, impulse type.

Dimensional, performance and cost data was received for these machines. The cycle plant arrangement can accomodate any of them by modifying the turbine generator platform. The standard 3,600 rpm speed should be applicable to the cycle plant size. However, if exact specific speed duplication of a full size turbine is required, a gear box may also be necessary.

The slide shows the Hitachi vertical axial flow turbine and dimensions. This turbine is similar in cross-section to the baseline full scale vertical turbine outlined in report LMSC-D056566. However, it is not considered important to simulate the full scale turbine arrangement in the cycle plant, i.e., a horizontal arrangement can provide identical performance data.

Efficiencies for these turbines are in the high eighties for most manufacturers. Rated efficiencies are for 99% ammonia vapor quality with each 1% reduction in quality resulting in about a 1% reduction in efficiency.

BATHTUB CONFIGURATION

LMSC and Bechtel agreed on two cycle plant concepts for investigation. These concepts were called the "bathtub" configuration and the "grade" configuration. System descriptions, specifications and drawings were produced for these configurations for 3 MWe, 6 MWe and 9 MWe "net" output cycle plants. Net output refers to the net output which the plant would have if it were located as an OTEC plant in the ocean. For the land based cycle plant, additional pumping power requirements actually result in auxiliary power requirements greater than the turbine/generator gross output.

The 6 MWe net bathtub configuration cycle plant shown originated from the desire to isolate the circulating water pumps from the intake structure pumps, i.e. to have an OTEC cycle plant operating solely between upstream and downstream open pools, totally isolated from external hydraulic effects. The depth of the dry "bathtub" between the inlet and outlet pools was necessary to satisfy the anticipated high NPSH requirements of the circulating water pumps and to avoid vortex formation by these pumps. Also, the bathtub allowed the installation of optional vertical heat exchangers (shown installed in the slide) with little or no additional pumping power requirements by using the bathtub depth in combination with siphon recovery into the outlet pool. The disadvantage of this configuration is the high civil/structural costs associated with the deep bathtub, primarily in the concrete walls and floor necessary to withstand external earth and hydrostatic pressures.

The "bathtub" configuration requires approximately 90 feet of excavation while the "grade" configuration requires 30 feet of excavation.

ALTERNATE EARTHWALL CONSTRUCTION

I-14

ALTERNATE EARTH WALL CONSTRUCTION

As an alternate to the concrete gravity dam wall construction shown in the previous slide, earthwall construction was briefly investigated. Although the expensive concrete walls are eliminated, excavation is increased and access is reduced. The heat exchanger weights are approximately 250, 450 and 650 tons for the 3, 6 and 9 MWe net cycle plants respectively. To service these heat exchangers, the overhead crane arrangement of the previous slide is replaced by a complex and space consuming crawler/track arrangement. This alternate bathtub arrangement was considered unwieldy and was not considered further.

GRADE CONFIGURATION

GRADE CONFIGURATION

The 6MWe net "grade" configuration shown was chosen as an alternate when it became apparent that the testing of large scale OTEC pumps in the circulating water loops may not be necessary, obviating the requirement for the dry bathtub for pump submergence reasons. Circulating water pumps are shown in the figure however. They can be tested by increasing the intake structure pump head to satisfy the circulating water pumps NPSH requirement and then dissipating this additional head by using an orifice plate downstream from the heat exchangers. The pumps can be replaced by spool pieces or passive swirl-producing sections. The outlet pool is retained to achieve siphon recovery when the circulating water pumps are not installed. The installation of vertical heat exchangers requires additional intake structure pump head and support structure for the heat exchangers; these being the major economic disadvantages of this configuration.

ALTERNATE CANTILEVER WALL CONSTRUCTION

ALTERNATE CANTILEVER WALL CONSTRUCTION

The civil/structural designs for the cycle plants shown in the previous slides were based on gravity dam concrete construction for the framework. When cycle plant cost estimates were prepared, it became apparent that the civil/structural costs utilizing this approach were out of line with regard to the overall plant estimate. The civil/structural design was therefore subjected to re-analysis and an alternate design, utilizing cantilever wall analysis, was developed. The revised design for the 6 MWe bathtub configuration is shown.

LBTF CYCLE PLANT CONFIGURATION COST COMPARISON

LBTF CYCLE PLANT CONFIGURATION COST COMPARISON

The bar graph shown in the slide compares the construction cost of the 6 MWe bathtub and grade cycle plant configurations. Both the gravity dam and cantilevered wall civil designs are depicted.

The construction cost includes the purchase and installation of equipment and materials for the cycle plant, intake structure, seawater piping system and plant auxiliaries. Excluded are the balance of the test facility support buildings and facilities.

The cycle plant costs are divided into major categories defined as follows:

Heat Exchangers: Purchase and erection of the cycle plant evaporator and condenser.

Mechanical and Electrical: Purchase and installation of turbine generator, intake structures pumps, circulating water pumps, equipment handling crane, all other mechanical equipment and all electrical equipment and materials.

Seawater Pipe: Purchase and installation of 2,000 linear feet of seawater pipe, intake structures, and discharge structures.

Civil/Structural: Excavation, concrete work and support steel required for the cycle plant.

Engineering Services: Engineering, home office cost and fee.

Allowance for Uncertainty: Allowance for the uncertainties that exist in quantity, pricing, productivity within the scope of the conceptual design.

LBTF CYCLE PLANT COST — EFFECT OF SCALE

LBTF CYCLE PLANT COST-EFFECT OF SCALE

The effect of cycle plant size on construction cost is presented for the grade configuration cycle plant utilizing a gravity wall civil design. The costs for plants of 3 MWe, 6 MWe, and 9 MWe "net" power output are shown.

The estimate scope and major cost categories are defined in the previous discussion of LBTF cycle plant configuration comparison.

TRADEOFF CONSIDERATIONS

- CIVIL/STRUCTURAL COST ASSOCIATED WITH THE EXCAVATED AND CONCRETE LINED TEST AREA
- STRUCTURAL COST ASSOCIATED WITH SUPPORTING THE HEAT EXCHANGERS ON THE TEST BED
- INITIAL COST OF INTAKE STRUCTURE PUMPS AND PIPING
- ENERGY COST DUE TO PUMPING HEAD
- INITIAL COST OF PIPING DUE TO TRANSIENT VACUUM CONDITIONS
- SPECIFIC SITE SOIL CONDITIONS AND GROUNDWATER SITUATION
- METHOD OF CONSTRUCTION APPLICABLE
- TYPE AND DIMENSIONS OF ALL HEAT EXCHANGERS TO BE TESTED
- UTILIZATION FACTOR FOR EACH OF THESE HEAT EXCHANGERS
- SITE DEPENDENT RELATIVE ELEVATIONS (INCLUDING VARIATIONS)
- COST OF ENERGY
- SIZE OF CYCLE PLANT
- APPROPRIATE CAPITALIZATION FACTOR
- AVAILABILITY OF CAPITAL

TRADEOFF CONSIDERATIONS

Based on the technical and cost information developed for the bathtub and grade configuration cycle plants, a 3 MWe "ducted open water loop" configuration was selected. This is similar to the grade configuration in that there is no upstream open pool. The tradeoff considerations to be evaluated in preliminary design were reviewed and are listed in the Figure.

For the LMSC baseline horizontal heat exchangers, there is little pumping power gain to offset the large civil/structural costs of a deep bathtub configuration since the discharge elevation is just below grade in either case. Vertical heat exchangers, however, would require considerably more pumping power for a grade configuration. As the utilization factor of vertical heat exchangers increases, energy cost would tend to lower the test bed floor optimum elevation. As the utilization factor of vertical heat exchangers decreases, however, civil/structural costs tend to raise this elevation. For purposes of this study, based on a brief review of the listed tradeoff considerations, an intermediate floor elevation of 30'-0 below grade was chosen for the conceptual design. This elevation should be reviewed and revised based on a more detailed analysis using specific site information.

SELECTED CONFIGURATION

I-26

SELECTED CONFIGURATION

The basic layout of the 3 MWe net cycle plant with LMSC baseline horizontal heat exchangers installed, and an intake structure with 3-4,000 HP pumps for the cold circulating water system is shown. A similar intake structure exists for the warm circulating water system.

The plant utilizes the cantilever wall construction discussed previously. A major change from the earlier grade configuration design is the removal of the discharge pond. The relatively expensive civil/structural cost of this pond has been eliminated by the use of an orifice/standpipe/control valve arrangement. Diameter of the standpipe has been tentatively set at the 10 feet diameter of the circulating water system pipe. However, transient hydraulic analysis is necessary to finally select its size.

Although testing of the baseline bulb type circulating water pumps in the cycle plant is probably not necessary, a transition section has been provided for possible pump installation. The intake structure pumps will be required to deliver the desired flow over a head range of approximately 40 to 120 feet depending upon the particular arrangement and type of heat exchanger being tested. Changes in pump head can be accomplished by either a variable speed drive or by changing the pump bowl and/or impellor possibly in conjunction with a two speed motor. Studies of several alternate pump options should be made when the vertical heat exchanger types and tests are better defined.

VERTICAL DOWNFLOW APL HEAT EXCHANGER ARRANGEMENT

I-28

VERTICAL DOWNFLOW APL HEAT EXCHANGER ARRANGEMENT

The 3 MWe net cycle plant test bed can be used to test different types of vertical heat exchangers in addition to the baseline LMSC horizontal heat exchangers. This is a version of the vertical downflow heat exchangers proposed by the John Hopkins University Applied Physics Laboratory (APL). The arrangement includes a free water surface above the heat exchangers as shown in the APL report "Analytical Study of Two-Phase-Flow Heat Exchangers for OTEC Systems" dated November 1975. Containment of the 16 ft. width, 16 ft. deep, 50 ft. high heat exchanger is not shown. Detailed designs may result in the heat exchanger being contained within a 24 ft. diameter tank.

The desired flow and free water surface level will be controlled by a combination of upstream pump speed or throttle control, and downstream discharge valve control. Energy will be dissipated across the downstream orifice and control valve.

VERTICAL DOWNFLOW LMSC PANEL HEAT EXCHANGER ARRANGEMENT

I-30

VERTICAL DOWNFLOW LMSC PANEL HEAT EXCHANGER ARRANGEMENT

This is a version of the LMSC panel type heat exchanger installed in the 3 MWe net cycle plant test bed. This arrangement is shown with a totally enclosed water passage with a maximum elevation of 70 feet above grade. Depending upon future analysis, the operating pressure in the pipe at this elevation may be approximately one atmosphere or may be at vacuum conditions to conserve pumping power requirements. The pressure at this point can be controlled by the downstream orifice and control valve. It may be more economical to provide a free water surface above the heat exchanger rather than an enclosed pipe. A free water surface would reduce vacuum transient effects occurring after pump trip out.

PIPING AND INSTRUMENTATION DIAGRAM

I-32

PIPING AND INSTRUMENTATION DIAGRAM

The basic cycle including the instrumentation and controls necessary to provide safe and continued plant operation are shown.

The cycle plant will be provided with a centrally located control room from which essential plant equipment and systems are controlled. The plant operator is provided with adequate information and controls in the control room to start-up, run at steady state and shutdown the main power cycle and major equipment. The operator is able to override selected automatic plant controls and operate the power cycle and selected system components at "off normal" conditions. No operator action is required during plant transients and no system or equipment protective function can be overridden.

The operating status of all machinery and indication of all system parameters essential for safe and continued plant operation will be displayed. The abnormal conditions and trips or failures of normally operating equipment will be annunciated in the control room. All control room mounted instrumentation will be electrical or electronic. All essential system variables will be displayed at the location of control devices (e.g., pump start hand switch - pump discharge header pressure indicator). The warm water and cold water circulating water flows will be measured using ultrasonic devices and smaller flows will be measured using the conventional head drop method across orifices or nozzles.

The turbine/generator supplied controls as well as other packaged systems control and instrumentation (compressed air, etc.) are integrated into the overall plant design and control.

The cycle plant controls are designed to minimize system transient loads, to protect the systems and associated equipment from water hammer, and to protect the major pumps from cavitation, prolonged operation at shut off heads and reverse rotation.

During normal plant operation, the turbine/generator power output varies as the thermal gradient of the circulating water systems changes. The turbine control vanes are adjusted to the optimum position for the operating flow rate. The condenser and evaporator levels are automatically maintained by make-up and reject valves and by a control valve at the discharge of the condensate pumps. A recirculating control valve is provided at the condensate pump discharge to assure a minimum flow when the evaporator level control valve is closed thereby avoiding pump overheating. The standpipe level control valve and the intake structure pumps discharge valves operate to maintain the desired circulating water flow and heat exchanger pressure.

AUXILIARY SYSTEMS

* CONDENSER WATER INJECTION	AREA DRAINAGE
* AMMONIA CLEANUP	AMMONIA TRANSFER
* NITROGEN PURGE	CIRCULATING WATER AIR REMOVAL
* TUBE CLEANING	ELECTRICAL
LUBE OIL PURIFICATION	EQUIPMENT HANDLING
COMPRESSED AIR	FIRE PROTECTION AND SAFETY EQUIPMENT
AUXILIARY COOLING WATER	CATHODIC PROTECTION
CONTROL SYSTEMS	
- * SYSTEMS INCLUDED TO ACCOMMODATE PARTICULAR OTEC TESTING REQUIREMENTS.

AUXILIARY SYSTEMS

In addition to the major equipment specifications and major systems descriptions, the cycle plant auxiliary systems shown were identified and described in sufficient detail to permit gross costing and to develop auxiliary power requirements.

Condenser water injection and ammonia cleanup were included to simulate the effects on the cycle of water inleakage to the condenser. This may occur in the baseline commercial plant since the external seawater pressure is greater than the internal ammonia pressure due to the considerable submergence of the condenser.

A circulating water air removal system is included to remove gases from the circulating water system when the heat exchangers are operating at vacuum conditions. Dissolved gases will come out of solution under these conditions and would accumulate in the heat exchanger water passages unless removed by the air removal system.

The ammonia transfer system includes a steam heated ammonia vaporizer to pressurize the condenser and evaporator with superheated ammonia vapor during system filling. Also, an ammonia cold trap will be used to reduce the amount of ammonia lost during venting of the non-condensable residual nitrogen after an ammonia fill has taken place and startup is initiated. The cold trap may include a vent gas compressor and a water/dry ice/refrigerator system ammonia condensation unit.

COST FOR 3 MW CYCLE PLANT

COST FOR 3 MW CYCLE PLANT

The construction cost of the 3 MW cycle plant are depicted by the bar chart.

The estimate scope and major cost categories are defined in the previous discussion of the LBTF cycle plant parametric study.

3 MW CYCLE PLANT CONSTRUCTION SCHEDULE

3 MW CYCLE PLANT CONSTRUCTION SCHEDULE

The slide shows the engineering and construction schedule for the 3 MWe selected cycle plant. The project can be completed within a 40 month period.

The governing factors are the ordering, manufacture, delivery and installation of the major mechanical equipment. The heat exchangers, turbine and circulating water pumps lead times are currently estimated by suppliers to be approximately 24 months.

TESTING II

LAND BASED TEST FACILITY SUPPORT

PRESENTED BY
GERALD G. JOHNSON

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING II - LAND-BASED TEST FACILITY SUPPORT

Site plan

Land-based test facility personnel

Building types

LBTF utilities systems

LBTF electric power requirements

Facility support - misc. equipment

Test facilities support cost

Cost for land-based test facility

Schedule for land-based test facility

Test facility constraints/risks

SITE PLAN

J-4

SITE PLAN

As depicted the site would require approximately 21 acres. Since a site has not been selected for the test facility the following assumptions were made: a) The site is slightly sloped and suitable for surface drainage with runoff collected in roadside ditches; b) The climate is temperate, free of snow and excessive rainfall; c) Soil is firm and free draining with the subgrade having a minimum bearing capacity of 2000 lbs. per square foot; d) A railroad main line track is available in the vicinity of the site from which a spur may be routed into the test facility; 3) Sources of warm and cold water exist to the north and a pump structure will be constructed providing the circulating water requirements for the cycle plant and cooling water for the test facility. Also, a free body of water, which can accept the water discharge is located to the south of the test facility; f) A sewer main is available to the north to receive the test facility sanitary discharge; g) A source of potable water exists to the north of the site; h) An access road, from a public traveled way, will enter the site from the west; i) Power to the facility substation will be transmitted from an existing utility grid located to the east of the site.

Buildings are generally grouped in accordance with their related functions. The shops, anticipated to handle the largest equipment loads, are located to the east and west of the railroad spur. The control building, instrument calibration lab, electric shop and central data system building complex is located adjacent to the cycle plant test bed and such that the two story control building overlooks the test bed and laydown area. The administration building area including the photo processing and analysis laboratories, the employee welfare building and the main parking lot are located adjacent to the site entry, to the west of and removed from the railroad and shop area. The location of some buildings such as the central data system, instrument calibration laboratory and electrical shop may provide more efficient operation being combined with the analysis and photo processing laboratories and located more centrally to the test beds. This alternative would change the large parking lot position and place the Data/Laboratories building next to the storage yard.

Asphalt surfaced roadways of widths varying from 12 to 50 feet provide access to the various buildings and test facilities. Roads are to be designed in accordance with ASSHTO-HS-20-44 loading with the wider roadways designed for exceptionally wide equipment such as crawler cranes.

The railroad spur and unloading spur will be designed in conformance with AREA standards and the carrier's specific requirements.

The site is protected by a 7'-0" chain link fence.

LAND-BASED TEST FACILITY PERSONNEL

<u>ADMINISTRATIVE *</u>	<u>ENGR/TECH*</u>	<u>SHOP/MAIN*</u>	<u>TEST OBSERVERS</u>
FACILITY MANAGER	TECH SUPERVISOR	FOREMAN	U. S. G.
PROGRAM ADMIN	TEST PERSONNEL	MACHINISTS	CONTRACTOR
PERSONNEL	ENGINEERS	MECHANICS	VENDOR
FINANCE	DESIGNERS	WELDERS	
SECURITY	TECHNICIANS	ELECTRICIANS	
SAFETY	LAB OPERATORS	CRANE OPTS	
EMPLOYEE SERVICES	COMPUTER OPERATORS	PAINTERS	
	DATA HANDLING	REC'G/SHIPPING	
	PHOTOGRAPHY	MAT'LS/STORES	
FACILITY REQ'T 17*	31*	28*	14
TEST REQ'T 39*	67*	58*	30

*PAYROLL

LAND-BASES TEST FACILITY PERSONNEL

The personnel complement for the test facility has been arranged into four categories, three of which are considered payroll as their permanent assignment is to work at the test facility. The fourth category is considered transient or temporary and are paid by off-test-site organizations.

Typical types and numbers of personnel are indicated on the chart. The facility requirement is based on the number of personnel spaces required at the test facility. The test requirement number is based on a 24 hour day, 7 days a week. The 24 hour day, 7 days a week was established as the test operation mode.

The totals are 90 for the test facility and 194 for test operations.

BUILDING TYPES

FOUNDATION PLAN &
PARTIAL GROUND FLOOR PLAN

ELEVATION

SECOND FLOOR PLAN

SECTION

PLAN

ELEVATION

SECTION

(CONTROL BUILDING SHOWN)
TYPE I

(ADMINISTRATION BUILDING SHOWN)
TYPE II

PLAN

ELEVATION

SECTION

(HEAVY MACHINERY SHOP SHOWN)
TYPE III

BUILDING TYPES

Sixteen support buildings are shown on the Site Plan and are categorized with respect to function as Types I, II & III as follows:

TYPE I - Reinforced concrete for structures requiring maximum interior environment controls. Interior partitions are steel studs with gypsum wall board on both sides.

1. Control Building - 50' x 80' - Two stories, housing the control consoles and data acquisition system. The ground level is designed as computer type floor, (rigid grid and pedestal system). Computer flooring may be used for the entire or partial area of the ground floor as required. Toilet facilities are included.
2. Central Data System Building - 40' x 40' - Single level, housing the computer equipment.

TYPE II - Prefabricated metal buildings with reinforced concrete foundations and floor slabs. Exterior walls and roof are "sandwich" panel type and the interior partitions are steel stud with gypsum wallboard on both sides. Exteriors and interiors are to be given architectural consideration compatible with the building function.

3. Administration Building - 80' x 80' - Single level, housing administrative offices and equipment, photo processing lab and analysis laboratory and toilet facilities.
4. Employee Welfare Building - 50' x 50' - Single level, to include: a first aid room, kitchen, cafeteria and toilet facilities.

TYPE III- Functional prefabricated metal buildings with reinforced concrete foundations and floor slabs. Exterior walls and roof are galvanized cold-formed sculptured panels with baked enamel finish. Interior partitions, where required, are steel studs with gypsum wallboard on both sides. Interior finishes are minimum required for the building function.

5. Heavy Machinery Shop - 100' x 180' with 50 ton crane.	11. Instrument Calibration Lab and Electric Shop 40' x 100' with toilet facilities.
6. Fabrication Building - 110' x 180' with 50 ton crane.	12. Gate House - 20' x 30'.
7. Pipe Shop - 100' x 100' with 10 ton crane.	13. Pump House (Hydraulic Test Pad) - 16' x 20'.
8. Paint and Sand Blast Shops - 40' x 90'.	14. Fire Pump House - 20' x 30'.
9. Receiving Shop - 100' x 100'.	15. Change House - 20' x 40' with toilets, showers and lockers.
10. Carpentry, Model and Maintenance Shops - 50' x 120' with toilet facilities.	16. Cycle Plant Aux. Equipment Building - 45' x 55'.

LBTF UTILITIES SYSTEMS

SYSTEM	CAPACITY
SANITARY SEWER	90 PERSON SITE OCCUPANCY
FIRE AND POTABLE WATER	1,000 GAL/MIN AT 75 PSI 90,000 GAL STORAGE TANK
PLANT COOLING WATER	294,000 GAL/MIN, 40 TO 120 FT HEAD
AMMONIA SUPPLY AND RETURN	70,000 LBS AMMONIA STORAGE AT 100°F AND 212 PSIA, 2,020 CU FT CYLINDER
NITROGEN SUPPLY	250 CU FT OF 2,000 PSIA CYLINDERS
DIESEL FUEL SUPPLY	6,000 GAL TANK
ELECTRICAL POWER	60 kVA SUBSTATION 13.8 kV, 3-PHASE, 60 CYCLE

UTILITIES

A drawing indicating routings and descriptive data relative to materials and sizes of piping and electrical cabling was developed for each of the listed utility systems adequate for conceptual cost estimating purposes.

The Sanitary Sewer System handles wastes from the tests beds, instrument calibration lab, change house, maintenance shop, the control, administration and employee welfare buildings. The system is gravity within the site and it is assumed a lift station is required at the north-west corner of the site and an off-site force main can be routed to an existing sanitary main. No special provisions were considered for handling possible excessive oil or caustic wastes at this time.

II-11

The Fire and Potable Water are combined in a single pipe system. The test facility is similar to plants that the National Fire Protection Association categorizes under Group 3 for which the basic requirements are 1000 gpm supplied in a plant loop system with a minimum hydrant pressure of 75 psi. An emergency diesel standby pump (1000 gpm - 75 HP - 120 psi) and a 90,000 gallon storage tank providing an emergency supply of 1-1/2 hours are also required. It is assumed that potable water can be delivered at a rate of 1000 gpm at 90 psi from a source near the site. Special fire protection requirements within the various test bed areas have also been considered.

The Plant Cooling Water System supply is from 3-350 HP pumps which are located in a structure adjacent to the cycle plant intake structure north of the plant site. It is brought to the site in a 60 in. ϕ prestressed concrete cylinder pipe and distributed to the hydraulic test bed, turbine test bed, heat exchanger test bed and the cycle plant test bed in smaller size pipes. After being used in the various test beds it is discharged from the site in a 60 in. θ prestressed concrete cylinder pipe to the discharge structure to the south of the site.

Ammonia, Nitrogen and Diesel Fuel will be shipped to the site by truck trailers or rail cars, unloaded into the storage tanks and distributed by pipe systems to the applicable facilities.

LBTF ELECTRIC POWER REQUIREMENTS

TEST FACILITY	POWER REQUIREMENT	
	MAXIMUM (KW)	AVERAGE (KW)
HEAT EXCHANGER TEST BED (0.25 MW)	1,186	600
HYDRODYNAMIC TEST BED	95	48
TURBINE TEST BED	33,118	16,600
SELECTED CYCLE PLANT (3 MW)	16,421	8,000
TOTAL	50,820	25,248

RECOMMENDED SUBSTATION CAPACITY = 60 MVA

LBTF ELECTRIC POWER REQUIREMENTS

This lists the estimated power requirements for the various test beds included in the Land Based Test Facility. Two columns are shown. The first column presents the maximum continuous power required by each test bed, with the total of 50,820 kWe being the maximum electric power demand for the entire test facility. To accommodate this total test facility electric load with margin for additional test site support load and power factor, a facility substation capacity of 60 MVA is recommended. The second column is an approximation of the expected average load for each test bed, with the total of 25,248 kWe being the approximate long-term average power consumption for the entire test facility.

The largest single electric power consumer in the test facility is the 31 MWe large motor used to drive the turbine/compressor string of the Turbine Test Bed. This single motor load represents greater than half of the total plant load.

FACILITY SUPPORT - MISC EQUIPMENT

ITEM	COST — \$K	
ADMINISTRATION FURNISHINGS _____		100
TECHNICAL GROUP OUTFITTING		
• INSTRUMENTATION / CALIB LAB _____	30	
• PHOTO LAB _____	10	
• TEST LAB _____	50	
• CONTROL BLDG _____	500	
TECH TOTAL _____		590
SHOPS _____		1,028
EQUIPMENT		
• HANDLING _____	778	
• STANDBY / MOBILE _____	213	
EQUIP TOTAL _____		991
UNDEFINED / CONTINGENCY _____		291
		3000

LAND-BASED TEST FACILITY EQUIPMENT COSTS

The cost of the equipment to furnish and outfit the buildings, shops, and laboratories are listed on this chart. The major cost is in the shops, followed by the handling and standby equipment. These two account for two-thirds of the total estimated equipment costs.

TEST FACILITIES SUPPORT COST

ITEM	\$ THOUSANDS
BUILDINGS	4,100
PLANT PIPING SYSTEMS	700
ELECTRICAL DISTRIBUTION SYSTEM	1,000
YARDWORK AND MISCELLANEOUS	600
TOTAL FIELD COST	6,400
ENGINEERING SERVICES	1,000
CONTINGENCY	1,600
TEST FACILITIES SUPPORT CONSTRUCTION COST	9,000
SUPPORT EQUIPMENT	3,000
TOTAL TEST FACILITIES SUPPORT COST	12,000

TEST FACILITIES SUPPORT COST

Tabulated are the construction cost of the facilities required to support the operation of the cycle plant and plant component testing facilities. The costs were divided into major categories defined as follows:

Building: Construction of the 16 office, shop, lab, and warehouse buildings required on the OTEC LBTF site.

Plant Piping Systems: Purchase and installation of fire and potable water, sewer and cooling water piping systems.

Electrical Distribution System: Purchase and installation of equipment and cable to distribute electrical power to the support facilities.

Yard Work and Miscellaneous: Site preparation, paving, fencing and landscaping.

Support Equipment: Purchase of office, shop and laboratory equipment.

COST FOR LAND BASED TEST FACILITY

LAND BASED TEST FACILITY CONSTRUCTION COST

The construction cost of the land based test facility is shown by the bar graph. The bar is divided into the construction costs corresponding to the five major components of the facility, as defined in the preceding discussion.

SCHEDULE FOR LAND BASED TEST FACILITY

J-20

ENGINEERING SERVICES

ENGINEERING

ENVIRONMENTAL REPORT

LONG DELIVERY PROCUREMENT

FIELD CONSTRUCTION

CYCLE PLANT

Civil/Structural

Mechanical

Piping

Electrical

Acceptance Testing

CRITICAL COMPONENT TEST BEDS

Civil/Structural

Mechanical

Piping

Electrical

Acceptance Testing

TEST FACILITIES SUPPORT

Civil/Structural

Piping

Electrical

— p and Office Equipment

LBTF ENGINEERING AND CONSTRUCTION SCHEDULE

The conceptual engineering and construction schedule shown for the LBTF indicates that the project could be completed within a 40 month period. The governing factor is the ordering, manufacture, delivery and installation of the cycle plant major mechanical equipment. This critical path is shown by a heavy line on the schedule.

The construction sequence and methods generally follow an approach to the construction of commercial plants which permits procurement and construction to commence before engineering is complete, thus shortening the schedule. The schedule is predicated on the economic use of manpower, as included in the conceptual estimate rather than the earliest possible completion date, although considerable parallel activity is included.

The schedule is divided into engineering services and field construction. The field construction is further divided into the major facility components as defined in the preceding discussions.

TEST FACILITY CONSTRAINTS/RISKS

- WATER RESOURCES – TEMPERATURES, FLOW RATES, QUALITY
- TOPOGRAPHY
- ENVIRONMENT – WEATHER
- TRANSPORTATION – EQUIPMENT AND PEOPLE
- AVAILABILITY OF SERVICES
- PUBLIC ACCEPTANCE
- LABOR POOL
- POWER GRID/SUPPLY
- UTILITY OPERATING PROCEDURES
- UTILITY INTERFACE PROBLEMS AND PENALTIES

TEST FACILITY CONSTRAINTS/RISKS

The listed land-based test facility constraints/risks have been identified. The major constraint is the water resources for the cycle plant. The land topography, which includes surface variations as well as soil conditions, is a major cost-sensitivity consideration. Extremes of granite or marshlands will increase the cost of the test facility considerably.

The weather and its influence on such things as building costs as well as the local aspects of transportation, utility and support services, public acceptance, and available labor pool are all constraints which must be resolved in the selection of the test facility site.

The final category of constraints/risks pertain to the local public utilities in terms of the potential restrictions on water or electrical power supply, utility operating procedures or conditions and interfacing problems and/or penalties associated with connecting to and using from or supplying to the utility. This includes the EPA impact.

TESTING II

SEA BASED CYCLE PLANT

PRESENTED BY
CHARLES M. ROBIDART

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING II - SEA BASED CYCLE PLANT

Sea-based cycle plant arrangement

Sea-based cycle plant auxiliary systems

Sea-based auxiliary system arrangement

Sea-based cycle plant cost comparison

Sea-based cycle plant schedule

SEA-BASED CYCLE PLANT ARRANGEMENT

SEA-BASED CYCLE PLANT ARRANGEMENT

This 6 MWe sea-based cycle plant has the cycle equipment and some auxiliaries mounted in a compact arrangement on an equipment base. The base can be mounted in a ship, barge or floating dry dock structure. However, a specific sea-going vehicle has not been included at this time. The cycle plant can be operated in either a dry or a wet environment depending upon the vehicle selected. A wet environment will require containment of some equipment to avoid contamination by sea water.

Sizes of power cycle equipment are the same as those of the land-based cycle plant.

To avoid recirculation, the warm and cold sea water discharges are located on the same side of the equipment base. Submergence of the 6 MWe cycle plant equipment is governed by an estimated minimum required pump submergence of 45 feet to avoid cavitation. The 65 feet submergence shown results in an equipment base elevation of 93 feet below sea water level and a top-of-turbine elevation of 2 feet above sea water level. Alternatively, the pumps could be mounted in intake pipes to the required depth with the heat exchangers and other equipment mounted on the base at a lesser depth.

If operation in a wet environment is selected, it is assumed that dry maintenance/access to the cycle plant can be accomplished by occasionally raising the vehicle or by pumping sea water from an enclosed space within the vehicle depending upon the vehicle selected. Some minor maintenance could also be performed by divers during operation.

SEA BASED CYCLE PLANT AUXILIARY SYSTEMS

- * CONDENSER WATER INJECTION
- * AMMONIA CLEANUP
- * NITROGEN PURGE
- * TUBE CLEANING
- LUBE OIL PURIFICATION
- COMPRESSED AIR
- COOLING WATER
- CATHODIC PROTECTION
- CONTROL SYSTEMS
- LEAK DETECTION AND FLUID SAMPLING
- SEAWATER PUMP POD PRESSURIZING
- AMMONIA TRANSFER
- ELECTRICAL
- GENERATOR POWER DUMP
- STARTUP POWER
- HYDRAULIC PRESSURE
- EQUIPMENT HANDLING
- FIRE PROTECTION
- * SYSTEMS INCLUDED TO ACCOMMODATE PARTICULAR OTEC TESTING REQUIREMENTS

SEA-BASED CYCLE PLANT AUXILIARY SYSTEMS

These are the major auxiliary systems required for operation of the sea-based cycle plant. Most of these auxiliary systems are similar to those of the land-based cycle plant and the full-scale baseline plant. Only the Generator Power Dump System and the Startup Power System are unique to the sea-based cycle plant.

The Generator Power Dump System is provided to dispose of the net plant power output. The power is dissipated to the ocean through an electrical load bank consisting of electrical resistors operated at 480 volts. Heat generated in these resistors is removed by fresh water circulating in a closed loop which, in turn, rejects the heat to an open sea water loop through a heat exchanger. A unique feature of the fresh water closed loop is that fresh water is vaporized in the load bank and then condensed in the sea water cooled heat exchanger. This feature, widely used in the industry, reduces the size and cost of the heat exchanger equipment.

The Startup Power Supply System is provided to supply auxiliary electrical power during plant start-up and to provide standby power during extended periods of plant shutdown. To provide flexibility and reliability of operation, two standard size 900 KW, 4,160 volt, diesel generators are provided.

SEA - BASED AUXILIARY SYSTEM ARRANGEMENT

K-8

SEA BASED AUXILIARY SYSTEMS ARRANGEMENT

Most of the cycle plant auxiliary equipment may be located on a surface support barge. The slide shows the arrangement of the barge-mounted auxiliary equipment only to the extent needed to determine approximate deck space requirements, since no specific support vessel is identified at this time.

Major equipment and facilities to be installed on the support vessel include control room, load bank for generator power dump, auxiliary transformers, switchgear, air compressor, diesel generators, ammonia storage and transfer equipment.

The support vessel is connected to the main vehicle by an umbilical cord. This cord will carry power cables, instrument and control cables, compressed air lines, ammonia fill and dump lines, and other fluid lines as required.

It should be noted that for certain types of main vehicles, a support vessel may not be necessary and the main vehicle may be able to accommodate all the auxiliary equipment.

The support vessel also provides space for photography laboratory; instrumentation; data acquisition and processing room; analysis laboratory; machine shop; maintenance shop and maintenance equipment.

SEA BASED CYCLE PLANT COST COMPARISON

6 MWe - \$1,000,000

	TEST PLATFORM					
	BARGE		TANKER		SEMISUBMERSIBLE	
OTEC EQUIPMENT	10.0		10.0		10.0	
COLD WATER PIPE	<u>1.5</u>		<u>1.5</u>		<u>1.5</u>	
		11.5		11.5		11.5
PLATFORM	1.3		7.0		35.0	
PLATFORM MODS	3.0		2.0		1.3	
EQUIPMENT	<u>4.2</u>		<u>4.2</u>		<u>4.2</u>	
		<u>8.5</u>		<u>13.2</u>		<u>40.5</u>
SUBTOTAL		20.0		24.7		52.0
CONTINGENCY	4.6		5.7		12.0	
ENG SERVICES	<u>3.0</u>		<u>3.7</u>		<u>7.8</u>	
		<u>7.6</u>		<u>9.4</u>		<u>19.8</u>
TOTAL		27.6		34.1		71.8

SEA-BASED CYCLE PLANT COST COMPARISON

The cost tabulation compares the estimated cost of a 6 MW_e cycle plant when compared to the total estimated capitalized cost of the cycle plant and the test platform. The purpose, even though the test facility study is test platform independent, is to show that the cost of the sea-based test facility is extremely dependent upon the test platform.

SEA - BASED CYCLE PLANT SCHEDULE

K-12

CYCLE PLANT SCHEDULE

The sea-based cycle plant schedule, shown by year, starts with go-ahead at beginning of the first year and ends with the cycle plant and the test platform ready for sea in the 45th month. The go-ahead date assumes all activity for issuing of an RFP, response evaluation, and contractor selection has been made and the go-ahead is the contractor start date.

Based on cycle plant size selection the engineering for the platform can commence along with the platform requirements leading to platform selection and commencement of platform modifications at the start of the 2nd year.

At contractor go-ahead the shore facility selection will be initiated in order to modify the facility to support the OTEC equipment fabrication and assembly.

Cycle plant activity will start with engineering in the third month in order to facilitate the long lead time equipment delivery. Assembly starts with completion of shore facility modifications and ends at the 36th month. Checkout is concurrent with the last 6 months of assembly in order to be completed by the 43rd or 44th month. A one to two month time cushion is provided for possible schedule slippage.

TESTING II

SEABASED TEST FACILITY SUPPORT

PRESENTED BY
CHARLES M. ROBIDART

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TESTING II - SEA-BASED TEST FACILITY SUPPORT

Topics

Sea-based test facility guidelines

Sea-based test facility site plot

Floating facility requirements

Coast Guard stability criteria

Deck area and hull volume

Logistic support

Sea-based test facility personnel

Sea-based test facility miscellaneous equipment costs

Sea-based test facility support costs

Schedule for sea-based test facility

Sea-based test facility constraints/risks

TOPICS

- GUIDELINES
- SITE PLOT
- FLOATING FACILITY REQUIREMENTS
- PERSONNEL
- EQUIPMENTS
- COST
- SCHEDULE

SEA-BASED TEST FACILITY SUPPORT

The seven main topics presented under the sea-based test facility support are guidelines, site plot, floating facility requirements, personnel, equipment, cost, and schedule.

The sea-based test facility support topics are presented with an option because of dockside land costs. The distinction is in the land test facility and shore facility. Case A provides a land test facility with all component test beds and their supporting activity contained in a single land plot within or adjacent to the shore facility (at dockside). The option, Case B, provides a land test facility with all component test beds and their supporting activity separate from shore facility. The shore facility, in Case B, has sufficient capability to support the at-sea test platform. Both Cases A and B include an at-sea test platform containing a cycle plant and a sea water pump test bed. The land test facility was established as the main administrative facility.

SEA BASED TEST FACILITY GUIDELINES

- SHORE BASED FACILITY PROVIDES COMPONENT BUILDUP AND CYCLE PLANT ASSEMBLY
- COMPONENT TEST BEDS WITHIN SHORE BASED FACILITY
- TEST PERSONNEL SPACE PROVISIONS IN SHORE FACILITY
- TEST PERSONNEL / MARINE CREW ROTATE AT SEA
4 WEEKS ON – 4 WEEKS OFF
- MAJOR EQUIPMENT CHANGES AT SEA

SEA-BASED TEST FACILITY GUIDELINES

The guidelines used in establishing the sea-based test facility support requirements are given here. The capability at the shore facility (which includes the dock) to provide component buildup and cycle plant assembly requires that heavy machinery, pipe, and fabrication shops be at the shore facility. This avoids potential major component transportation problems.

The heat exchanger, turbine, and sea water hydrodynamic component test beds are as stated previously and are part of the land facility which itself is either part of the shore facility or as a separate test facility.

The shore facility has space provisions for test personnel who are assigned to assist the at-sea test platform. The personnel who are assigned sea duty will rotate either on a 2 week on - 2 week off basis or a 4 week on - 4 week off basis.

To maximize the test platform at-site (on-station) time equipment changes will be accomplished at sea with a load limit of 200 tons.

SEA-BASED TEST FACILITY SITE PLOT

OPTION A

OPTION B

AT-SEA
SITE

BARGES

SUPPORT

CRANE

TEST
PLATFORM

SUPPLY
SHIP

8-T

SEA-BASED TEST FACILITY SITE PLOT

The site plot shows the relationship of the at-sea test site to the shore and land facilities. In general the land-based test facility conditions and results apply to the land portions of the sea-based test facility. The dock capacity must accommodate the largest of the barges or test platform or supply ship as well as the weight/size imposed by either the condenser or evaporator, plus the cranes used to hoist these items on-board the test platform.

Shown are the at-sea test platform with supporting vessels and the two options for land. At top right is Option A, which indicates the land test facility is part of the shore facility. At bottom right is Option B with the land test facility separate from the shore facility.

FLOATING FACILITY REQUIREMENTS

STABILITY

- COAST GUARD STABILITY CRITERIA
- OTHER REGULATORY BODIES

HULL VOLUME

- TEST AND TEST SUPPORT EQUIPMENT
- CREW AND TEST PERSONNEL ACCOMMODATIONS
- STORES AND SUPPLIES
- BALLAST, FUEL AND POTABLE WATER TANKS
- AUXILIARY POWER, MACHINERY, SHOP AREA
- MOORING SYSTEM

DECK AREA

- TEST AND TEST SUPPORT EQUIPMENT
- CREW AND TEST PERSONNEL ACCOMMODATION
- STORES AND SUPPLIES
- AUXILIARY POWER, MACHINERY, SHOP AREA
- MOORING SYSTEM

SEAKEEPING

- SAFETY OF VESSEL AND PERSONNEL
- PERFORMANCE OF MISSION
- VESSEL UNDERWAY

LOGISTIC SUPPORT

- CREW/SUPPLY VESSEL
- SERVICE BARGES
- TUGS

FLOATING FACILITY REQUIREMENTS

Provisions under the code of federal regulations Title 46 - Shipping require that vessels which fall within a certain classification must satisfy certain stability standards. These standards are promulgated by the Coast Guard which must be met before the Coast Guard will approve the vessel for the intended service. A stability test or stability calculations or both may be required by the Coast Guard before approval is given.

Other regulatory bodies which must be satisfied are:

- International Conventions for the Safety of Life at Sea (SOLAS)

Damage stability - the vessel shall have sufficient stability to withstand flooding after damage and to limit the amount of heel in order to provide reasonable assurance of the survival of the ship and the ability to launch the lifeboats.

Fire protection - provisions for alarm systems, fire-extinguishing apparatus, and fire-retarding materials for internal divisional bulkheading.

- Internal Load Line Conventions (ILLC)

The assignment of a load line or freeboard to the test platform will, in all likelihood, not be necessary in view of its mission. However, it is important that there is sufficient freeboard to insure an adequate stability range.

- Classification Societies

Several Classification Societies operate throughout the world, all of which publish rules and regulations relating primarily to the structural efficiency of the ship and the reliability of the machinery. It is not mandatory that a ship be designed and built in accordance with these rules, but in doing so the ship owner is in a better position to find a marine underwriter for his ship.

COAST GUARD STABILITY CRITERIA

- REQUIRED MINIMUM METACENTRIC HEIGHT (GM) – INTACT CONDITION

$$GM = \frac{PAh}{\Delta \tan \theta} \quad (\text{WEATHER CRITERIA})$$

- METACENTRIC HEIGHT FOR SEVERAL VESSEL TYPES (TYPICAL)

<u>SHIP TYPE</u>	<u>COAST GUARD MIN. REQ'D GM-FT</u>	<u>DESIGN GM-FT</u>
CARGO SHIP _____	0.29 _____	4.6 (LOADED)
TANKER _____	0.44 _____	6.6 (LOADED)
BARGE _____	1.15 _____	11.6 (LOADED)
DRYDOCK (AFDB) _____	0.57 _____	54 (11.25 DRAFT)
HMB _____	3.40 _____	141 (8 FT DRAFT)
	0.15 _____	21 (52 FT DRAFT)
SEMI-SUBMERSIBLE _____	1.00 _____	20 (60 FT DRAFT)

- DAMAGE CONDITION

SUFFICIENT INTACT STABILITY IN ALL SERVICE CONDITIONS TO ENABLE VESSEL TO WITHSTAND FLOODING AT ANY PLACE THROUGHOUT ITS LENGTH.

COAST GUARD STABILITY CRITERIA

The Coast Guard stability criteria, which are discussed in the Code of Federal Regulations Title 46 - Shipping, Part 74, states briefly that the minimum metacentric height (GM) in feet at any particular draft is to be obtained from the expression shown. This expression is fundamentally a weather criteria in that the value (P) is the wind pressure acting on the projected lateral area (A) of the portion of vessel above the waterline and which has a moment arm of (h) taken as the vertical distance from the center of (A) to the center of the underwater lateral area. (Δ is displacement and θ is roll angle.) The expression applies to the ship in the intact condition. Damaged stability standards have also been set down by the Coast Guard in which the stability of the vessel is determined for various flooding conditions.

The tabulated metacentric heights (GM) shown are for several different vessel types in the intact condition. The calculated Coast Guard minimum required GM is based on the vessel in the loaded condition and operating in partially protected waters (relatively low wind velocities). Design static metacentric heights are shown for each of the vessels for comparison.

It is customary in the design of a new vessel to calculate and plot a set of cross-curves of stability over a range of heel angles (0 to 90°) for several displacements. The data enable the ship's master to evaluate the ship's stability in the event of damage and to perform counterflooding measures.

Certain vessels, such as the deck barge and semi-submersible, are subject to a special criteria by the Coast Guard in which the area under the righting arm curve must be equal to or greater than the area under the wind heeling moment curve.

DECK AREA AND HULL VOLUME

<u>SPACE</u>	<u>DECK AREA SQ. FT.</u>	<u>VOLUME CU. FT.</u>
• TEST AND TEST SUPPORT EQUIPMENT _____	16,900	676,000
• CREW AND TEST PERSONNEL ACCOMMODATIONS		
BERTHING, WASHROOM AND TOILETS _____	4,300	30,100
MESSROOMS _____	640	4,480
GALLEY/SCULLERY/CREWS' PANTRY _____	400	2,800
HOSPITAL _____	145	1,015
LAUNDRY _____	33	231
RECREATION _____	660	4,620
• STORES		
POTABLE WATER _____	—	6,500
DRY _____	180	1,260
REFRIGERATED _____	290	2,030
STEWARD _____	81	567
BCSUN _____	50	350
ENGINEER _____	154	1,078
• AUXILIARY POWER AND MACHINERY SPC. _____	1,664	20,000
• MACHINE SHOP/ELEC. STORES _____	355	2,485
• FUEL-DIESEL _____	—	23,000
• AMMONIA TANK _____	—	3,500
• MOORING SYSTEM _____	DEPENDENT ON PLATFORM SELECTED	
• BALLAST _____	DEPENDENT ON PLATFORM SELECTED	
• RADIO ROOM _____	120	840
• CHART ROOM _____	64	448
• PILOT HOUSE _____	80	560
• ELECTRICAL DIST. CENTER _____	180	1,260
• COMPUTER ROOM _____	300	2,100
<u>CYCLE PLANT - 6 MW_e</u> _____	11,200	1,040,000
<u>CYCLE PLANT SUPPORT</u> _____	5,200	156,000

DECK AREA AND HULL VOLUME

The deck areas and hull volumes for the various spaces aboard the floating test platform are gross in that they include passageways and working areas. All volumes are based on a 7-ft overhead height for the space except for the auxiliary power and machinery space which is 12-ft and test equipment and cycle plant which are 40 and 115 ft, respectively.

The deck areas for crew and test personnel sleeping accommodations, washroom and toilets, and hospital are in accordance with the U. S. Coast Guard manning regulations. The size of the crew while set at 26 will be determined by a joint conference between owners, union, and U. S. Coast Guard representatives. Test personnel for conducting the tests and maintaining the equipment was set at 28. Additional space was provided for the accommodation of four government and six vendor representatives.

The officers' messroom was sized to accommodate all senior people on board as well as the visitors. Crew and test personnel messroom was sized to serve one-half of the members resulting in two mess servings.

A 30-day supply of potable water and a 90-day supply of diesel fuel have been provided. These amounts may be increased depending upon the platform selected. Dry and refrigerated stores are also based on 30 days.

The make-up ammonia storage tank was sized to provide one and a half charges (fills).

Deck areas and volumes for the ballast and mooring system were not specified in that they are highly dependent on the type of platform selected.

LOGISTIC SUPPORT

- SUPPLY
 1. CREW AND FOOD SUPPLIES
 2. FUEL OIL
 3. POTABLE WATER
 4. EQUIPMENT (2000 LBS)
 5. POWER PLANT WORKING FLUID
 6. MOORING LINE AND ANCHOR(S)
- CRANE BARGE
 1. HANDLING OF TEST EQUIPMENT
 2. HANDLING OF MOORING EQUIPMENT
 3. HANDLING OF COLD WATER PIPE
- BARGE
 1. TRANSPORTATION OF LARGE PIECES OF TEST EQUIPMENT
 2. TRANSPORTATION OF MOORING SYSTEM
 3. TRANSPORTATION OF COLD WATER PIPE
- TUG
 1. TOWING OF TEST PLATFORM
 2. TOWING OF BARGES

LOGISTIC SUPPORT

Logistic support for the floating facility will consist of such vessels as a supply ship, crane barge, barges, and tugs. Supply ships of the type being used extensively in offshore oil drilling operations would be ideal. These vessels are about 150 to 200 ft long and have a horsepower range of 2500 to 8000. Speed range is from 12 to 16 knots. From all indications the vessels perform very well in rough weather. The larger vessels have a generous deck area for carrying cargo up to 500 tons and a below deck tankage of some 23,000 cu ft. These vessels are also being employed as tugs for moving large oil drilling rigs.

It is anticipated that the removal and installation of major test components will be infrequent so that the use of a crane barge has an economic advantage over a permanently mounted crane on the test platform. A crane barge of 200 ton lift capacity and a boom length of 150 ft will be required. The services of a crane barge may be necessary for the installation of the cold water pipe and the deployment of the mooring system. The size and weight of these components as well as the available deck space and handling gear on the test platform are factors which must be considered in determining whether a crane barge is required. Most crane barges are non-self propelled and therefore will require the services of a tug.

Deck space aboard the test platform for such components as the cold water pipe and the platform mooring system may not be available and therefore will require the services of a barge. Deck cargo barges are readily available in many sizes and deadweight capacities. A possible alternate approach is to make use of the crane barge providing sufficient deck space exists.

Tugs are needed to place the test platform on station, unless however, the platform selected has a propulsion system. Movement of the barges and barge crane will also require the services of tugs.

SEA BASED TEST FACILITY PERSONNEL

	<u>ADMIN*</u>	<u>ENGR/TECH*</u>	<u>SHOP/MAIN*</u>	<u>MARINE* CREW</u>	<u>TEST OBSERVERS</u>	<u>TOTAL</u>
OPTION A - LAND TEST FACILITY AT SHORE FACILITY						
LAND/SHORE FAC.	16	28	22	—	14	80
LAND/SHORE TEST	34	50	47	—	30	161
AT SEA	<u>6</u>	<u>18</u>	<u>10</u>	<u>26</u>	<u>6</u>	<u>66</u>
TOTAL W/ROTATION	46	86	67	52	42	293
OPTION B - LAND TEST FACILITY SEPARATE FROM SHORE FACILITY						
LAND FAC.	16	25	20	—	10	71
LAND FAC. TEST	29	49	34	—	20	132
SHORE FAC.	9	7	12	—	4	32
SHORE FAC. TEST	19	10	16	—	14	59
AT SEA	<u>6</u>	<u>13</u>	<u>10</u>	<u>26</u>	<u>6</u>	<u>66</u>
TOTAL W/ROTATION	60	95	70	52	46	323

*PAYROLL

SEA-BASED TEST FACILITY PERSONNEL

The personnel complement for the test facility is arranged into five categories and two groups. The four asterisked categories are considered payroll as their permanent assignment is to work at the test facility. The fifth category is considered transient or temporary and are paid by off test-site organizations.

The content of each category is the same as given for the land-based test facility except for the marine crew whose structure provides for the operation of the test platform, safety of personnel at sea, and hotel services for all personnel at sea.

The facility requirement is the number of personnel spaces required at the test site or facility. The test requirement is based on a 24 hour day, 7 days a week. The at-sea crew quantity is for one crew.

The column total noted "W/Rotation" is the land/shore facility test number plus the two at-sea crews which are rotated equal time on and equal time off. For the land facility separate from the shore facility the total is the land facility test plus shore facility test plus 2 at-sea crews. The sea-based test facility personnel total is approximately 100 more than the land-based test facility. Splitting the land portion into land facility and the shore facility adds approximately 30 to the total head count.

SEA-BASED TEST FACILITY MISCELLANEOUS EQUIPMENT COSTS

LAND FACILITY AT SHORE FACILITY (\$1000)

ITEM	LAND FACILITY		TEST PLATFORM		TOTAL
ADMINISTRATIVE FURNISHINGS		100		—	100
TECHNICAL GROUP OUTFITTING					
• INSTRUMENTATION/CAL' B. LAB	30		15		45
• PHOTO LAB	10		5		15
• ANALYSIS LAB	50		25		75
• CENTRAL CONTROL	150		350		500
TECH TOTAL		240		395	635
SHOPS		1028		173	1201
EQUIPMENT					
• HANDLING	778		125		903
• STANDBY/MOBILE	213		135		348
EQUIP TOTAL		991		260	1251
UNDEFINED/CONTINGENCY		226		87	313
TOTAL		2585		915	3500

SEA-BASED TEST FACILITY MISCELLANEOUS EQUIPMENT COSTS

The cost of the equipment to furnish and outfit the buildings, shops, and laboratories noted on the previous chart are listed on the next two charts. The first chart is for the land facility at the shore facility and the second chart is with the land facility separated from the shore facility. As in the land-based test facility, the majority of costs are in the shops and handling and standby equipment. These two account for about 70 percent of the total estimated equipment costs.

SEA-BASED TEST FACILITY MISCELLANEOUS EQUIPMENT COSTS

LAND FACILITY SEPARATE FROM SHORE FACILITY (\$1000)

ITEM	LAND FACILITY		SHORE FACILITY		TEST PLATFORM		TOTAL
ADMINISTRATIVE FURNISHINGS		100		25		—	125
TECHNICAL GROUP OUTFITTING							
• INSTRU/CALIB LAB	30		—		15		45
• PHOTO LAB	10		—		5		15
• ANALYSIS LAB	50		—		25		75
• CENTRAL CONTROL	150		—		350		500
TECH TOTAL		240		—		395	635
SHOPS		928		847		173	1948
EQUIPMENT							
• HANDLING	778		712		125		615
• STAND BY/MOBILE	213		78		135		426
EQUIP TOTAL		991		790		260	2041
UNDEFINED/CONTINGENCY		326		238		87	651
TOTAL		2585		1900		915	5400

This page was intentionally
left blank

SEA-BASED TEST FACILITY SUPPORT COST

(\$1000)

ITEM	LAND FAC AT SHORE FAC.			LAND FAC. SEPARATE FROM SHORE FAC.			
	LAND	AT-SEA	TOTAL	LAND	SHORE	AT-SEA	TOTAL
BUILDINGS	4100		4100	3600	2000		5600
PLANT PIPING	500		500	500	100		600
ELECTRICAL DIST.	1000		1000	800	200		1000
YARD WORK & MISC.	900		900	600	300		900
TOTAL FIELD COSTS	6500		6500	5500	2600		8100
ENGINEERING SERVICES	1000		1000	800	400		1200
CONTINGENCY	1600		1600	1400	600		2000
TEST FAC SUPPORT							
CONSTRUCTION COST	9100		9100	7700	3600		11300
SUPPORT EQUIP	2585	915	3500	2585	1900	915	5400
TOTAL TEST FACILITIES							
SUPPORT COSTS	11685	915	12600	10285	5500	915	16700

SEA-BASED TEST FACILITY SUPPORT COST

Tabulated are the construction and support equipment costs of the facilities required to support the operation of the at-sea cycle plant and sea water pump component test bed and the component test beds located on land. The costs are grouped into the two options of the land facility at the shore facility and the land facility separated from the shore facility.

The building costs are for 15 office, shop, laboratories, and warehouse buildings required on land for the combined land-shore facility or for 24 buildings with the land facility separated from the shore facility.

The piping system provides for purchase and installation of fire and potable water, sewer, and cooling water piping systems.

Electrical distribution includes purchase and installation of equipment and cable to distribute electrical power to the buildings, shops, and test beds.

Yardwork and miscellaneous includes site preparation, paving, fencing, and landscaping. The support equipment is the purchase of office, shop, laboratory, and handling equipment as given on the previous chart.

SCHEDULE FOR SEA BASED TEST FACILITY

L-26

SEA-BASED TEST FACILITY ENGINEERING AND CONSTRUCTION SCHEDULE

The conceptual engineering and construction schedule shown for the Sea-Based Test Facility indicates that the project could be completed within a 42 month period. The governing factors are the definition, ordering, manufacture, delivery, and installation of the cycle plant major mechanical equipment.

The construction sequence has been divided into the major facility elements of shore, land, and test platform. The shore facility includes the dock, buildings, and equipments to fabricate the equipment to go onboard the test platform. The Land Facility includes the component test beds, buildings, and equipments for administration of the integrated test program as well as conduct component tests and, as required, AR&T experiments. The test platform holds the cycle plant and at-sea component test beds.

The construction sequence and methods generally follow an approach used in commercial plants which permit procurement and construction to commence before engineering is complete, thus shortening the schedule. The schedule is predicated on economic use of manpower, as included in the conceptual estimate rather than the earliest possible completion date, although considerable parallel activity is included.

SEA BASED TEST FACILITY CONSTRAINTS / RISKS

- SHORE BASED FACILITY LAND AVAILABILITY AND COST
- SHORE BASED FACILITY TOPOGRAPHY AND WEATHER
- AT-SEA FACILITY WEATHER
- LOGISTIC SUPPORT AVAILABILITY AND COST
- TRANSPORTATION-EQUIPMENT AND PEOPLE
- AVAILABILITY OF SERVICES
- PUBLIC ACCEPTANCE
- LABOR POOL
- POWER GRID / SUPPLY
- UTILITY OPERATING PROCEDURES
- UTILITY INTERFACE PROBLEMS AND PENALTIES

SEA-BASED TEST FACILITY CONSTRAINTS/RISKS

The sea-based test facility constraints/risks are very similar to those identified for the sea-based cycle plant with the addition of the availability of the dockside land and the cost of the dockside land. In addition to the location of the shore facility topography suitable for buildings and assembly of OTEC components is the constraint of weather and adequate dock size to accommodate the components of the OTEC cycle plant and the test platform.

The logistics aspects which constrain the sea-based test facility are primarily those of distance and the capability of replacing cycle plant components. Included are personnel constraints based on type of worker requirements (laborers, technicians, engineers), the on-board work shifts, and the crew or work rotation cycles.

The availability of services and public acceptance for the land-based portion is a potential constraint and must be considered in selection of shore and land facilities.

The power grid and power supply, utility operating procedures, and interfacing problems are dependent on the local utility's policies and procedures.

DATA ACQUISITION AND CONTROL SYSTEM (DACS)

PRESENTED BY
CHARLES M. ROBIDART

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

DATA ACQUISITION AND CONTROL SYSTEM (DACS)

DACS objectives

DACS alternatives

DACS simplified system diagram

DACS cycle plant simplified diagram

Land-based test facility data acquisition system costs

Sea-based test facility data acquisition and control system

Sea-based test facility data acquisition system (Costs)

Data acquisition system schedule

DACS OBJECTIVES

- DATA ACQUISITION AND DATA PROCESSING
- CONTROL OF CYCLE PLANT AND COMPONENT TEST AREA OPERATIONS
- FACILITY OPERATIONS
- REAL TIME DATA ANALYSIS AND PRESENTATION
- ENGINEERING ANALYSES

DATA ACQUISITION AND CONTROL SYSTEM OBJECTIVES

The objectives of the Data Acquisition and Control System (DACS) were defined to acquire and produce quality data from five test areas (one of which is the cycle plant); to provide test area control capability including control of facility equipments and operations pertaining to the test areas; to provide real-time data analyses for on-the-spot calculation of components and systems being tested and the test conditions; and to provide the engineers and test operators the capability of performing analyses, evaluate and predict test conditions, and interpret results.

The land-based DACS was established as being a general-purpose service system capable of providing support simultaneously to several test areas and a small cycle plant with independent operation of individual tests. Large quantities of information must be gathered from numerous measurement points and processed to provide data to evaluate the performance of OTEC components and systems being tested. The DACS system must simultaneously present selected data to operators and test conductors to properly execute test operations. The DACS system, as configured or selected by the test operations conductor, must also be capable of performing closed-loop automatic control or manual control of the test being conducted or facility equipment being operated.

DACS ALTERNATIVES

- CENTRALIZED VERSUS DECENTRALIZED COMPUTER
- GROWTH POTENTIAL – TO EIGHT TEST AREAS
- COMMUNICATIONS RECORD
- SECONDARY FUNCTIONS

DACS ALTERNATIVES

The major alternative considered was centralized vs. decentralized system, i. e., should the system be a centralized computer complex within the facility which performs all functions via remote terminals and consoles at the test area and cycle plant or should the system be decentralized with smaller general-purpose computers at each control room for the test areas and cycle plant? Results based on cost and past experience on similar installations by Lockheed Electronics Company show that a multifunction large facility needs a centralized computer system. This approach provides more capability and flexibility at lower cost through better utilization of the data processing equipment and data and program storage equipment.

Secondary DACS alternative considered the growth potential to eight test areas (allowing for future facility or test area growth) and the control of communications within a test area and between test areas in order to assure test coordination and the recording of pertinent time-phased information during normal operation as well as in the event of malfunction or breakdown. Also considered was the capability of providing secondary functions of material inventory and accounting, operations scheduling, test reports and procedures, and even personnel records and payroll.

DACS SIMPLIFIED SYSTEM DIAGRAM

M-8

DACS SIMPLIFIED SYSTEM DIAGRAM

The DACS concept consists of test area terminal equipment, test area control room equipment, and a central processing facility. A typical test area terminal and control room are shown. The test area terminal equipment is the DACS terminal and a portable calibration and test unit (the terminal interfaces the test article to the central computer, and the test unit provides control and sensor signal test and checkout and end-to-end test of the DACS prior to initiating the test). The test area control room equipment is the control console containing the keyboard, CRT display, manual controls and dedicated displays, and the hard copy devices. The central processing facility contains dual computers; computer operator terminal; data storage, recording, and plotting peripherals; and computer software.

6-M

In the manual mode, all control inputs are via the control console. Data logging configuration of the central facility will be accomplished via the central facility operator upon request from the test conductor. The test conductor has parameter call-up capability via the control room keyboard. The parameter(s) is displayed on the CRT and if required, printed hardcopy by keyboard command. Dedicated displays are presented on the test area console for control parameters for the particular test.

In automatic control the dedicated displays are presented for the test operator. Specific test configuration and parameter set points can be entered via test area console keyboard. Quick-look parameter data can be called by test point number and page entry via the keyboard. The test area control room plotter output is optional, as the plots are made in the central facility along with short- and long-term data storage.

DACS CYCLE PLANT SIMPLIFIED DIAGRAM

M-10

DACS CYCLE PLANT SIMPLIFIED DIAGRAM

The cycle plant utilizes the central dual computer facility for logging all parameters and for computing control parameter values based on feedback sensor inputs from the remote terminal. The cycle plant operations room is utilized to monitor the cycle plant operation. Cycle plant operations will be automated and under computer control because of the many control parameters to be monitored and the expected long-term system operation. Display boards and color graphics will be used in addition to CRT and dedicated parameter displays to assist operators and visitors to visualize the plant operation. Plant performance at nominal parameter values will be tested as well as performance sensitivity to parameter variations. The off nominal parameter set points may be entered via keyboard from the cycle plant control room.

LAND BASED TEST FACILITY DATA ACQUISITION SYSTEM COSTS

COST \$1000

ITEM	CENTRAL + CYCLE PLANT + 4 TEST AREAS		CENTRAL + CYCLE PLANT + 8 TEST AREAS	
<u>EQUIPMENT</u>				
● CENTRAL PROCESSOR	821	1115	977	1393
● CONSOLES	120		173	
● TERMINALS	174		243	
EQUIPMENT TOTAL				
<u>PERSONNEL</u>				
● HARDWARE DEVELOPMENT	446	1062	754	1466
● SOFTWARE DEVELOPMENT	616		712	
PERSONNEL TOTAL				
<u>CONTINGENCY</u>		323		441
<u>TOTAL</u>		2500		3300

UTILITY PACKAGE 60

LAND-BASED TEST FACILITY DATA ACQUISITION AND CONTROL SYSTEM COSTS

The costs of the land-based test facility data acquisition and control system are presented for the baseline system of the central processing facility, the cycle plant and four test areas and for the option of the central processing facility, one cycle plant and eight test areas. The equipment costs are for the procurement of hardware, while the personnel costs are for engineering and programming manpower. The contingency includes the preparation of the DACS requirements specification, detailed listing of programs, etc.

The cost increase in adding the four test areas assumes the four test areas are incorporated into the system at the same time. The cost increases if the eight test areas are incorporated at the same time as the central processing will be slightly less and if accomplished individually at different times, will be slightly more than the differential shown for the four test areas.

The utility package priced at the bottom of the chart is the cost of the option for the secondary features of material inventory and accounting, operations scheduling, personnel records, and payroll.

SEA BASED TEST FACILITY DATA ACQUISITION AND CONTROL SYSTEM

- OBJECTIVE – SAME AS LAND BASED TEST FACILITY
- GUIDELINES
 - LAND FACILITY – MAIN DATA PROCESSING FACILITY
 - REDUCED ENGINEERING ANALYSIS AT-SEA
 - NO DIRECT DATA LINK LAND-SEA
- CONFIGURATION
 - TEST PLATFORM
 - REDUCED CENTRAL PROCESSING
 - CYCLE PLANT
 - TEST AREA
 - LAND FACILITY
 - REDUCED CENTRAL PROCESSING
 - FOUR TEST AREAS

SEA-BASED TEST FACILITY DATA ACQUISITION AND CONTROL SYSTEM

The objectives of the DACS for the at-sea test platform is the same as the land-based test facility. DACS must acquire and process data; control the cycle plant and component test area; control equipment operations pertaining to the cycle plant and test area; provide real-time data analysis and presentation; and provide engineering analysis capability.

The guidelines for the sea-based test facility DACS are based on the definition given to the functions to be performed on the test platform versus the land facility. The emphasis on engineering analysis will be at the land facility, however the at-sea capability will be sufficient for excepted performance predictions and diagnostic calculations. No provisions are furnished for a direct data link between the test platform and the land facility. Normal communications will be used for engineering assistance from the land facility to the test platform.

The at-sea cycle plant and test area capability will be the same as in the land-based test facility but central processing will be reduced as there is only one test area versus four test areas on land. The same rationale applies to the land facility as the cycle plant is no longer there.

SEA BASED TEST FACILITY DATA ACQUISITION SYSTEM

COST \$1000

ITEM	TEST PLATFORM CENTRAL + CYCLE PLANT + 1 TEST AREA		LAND FACILITY CENTRAL + 4 TEST AREAS	
<u>EQUIPMENT</u>				
● CENTRAL PROCESSOR	424		558	
● CONSOLES	111		82	
● TERMINALS	106		211	
EQUIPMENT TOTAL		641		851
<u>PERSONNEL</u>				
● HARDWARE DEVELOPMENT	175		264	
● SOFTWARE DEVELOPMENT	195		449	
PERSONNEL TOTAL		370		713
<u>CONTINGENCY</u>		164		216
<u>TOTAL</u>		1175		1780

SEA-BASED TEST FACILITY DATA ACQUISITION AND CONTROL SYSTEM COST

The cost of the sea-based test facility data acquisition and control system is presented with the test platform and the land facility parts. There is an increase of about \$375,000 for equipment over the land-based test facility (4 test areas) and only \$20,000 for personnel. The contingency increases as the requirements specification is more complicated.

DATA ACQUISITION SYSTEM SCHEDULE

DATA ACQUISITION SYSTEM SCHEDULE

The schedule shown for the design, preparation, and checkout of the Data Acquisition and Control System (DACS) is based on authorization to proceed being obtained by mid-1978. Since the system is based on available technology, the hardware can be obtained in a reasonable span and no long-lead-time items are presently considered.

The initial DACS installation will be designed for use with the Component Test Facility. Additional equipment and computing capability will be provided for use with the cycle plant. This approach and the time spans shown are flexible enough to provide compatibility with the selections of either a land-based or sea-based cycle plant.

OTEC TEST FACILITY COST ESTIMATES

PRESENTED BY
R. J. PONT

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TEST FACILITY/COST ESTIMATES

Introduction to costs

Basis of estimates

Subsystem estimates

Cycle plant estimates – introduction

Land based cycle plant cost

Shore based cycle plant cost

Sea based cycle plant cost

6 MW cycle plant cost comparison

At sea test platform

Component test cost

Advanced research & technology cost

Land based test facility support cost

Sea based test facility support cost

Land based test facility cost summary

Shore based test facility cost summary

Sea based test facility cost summary

6 MW test facility cost comparison

INTRODUCTION TO COSTS

- BASIS OF COST ESTIMATES
- SUBSYSTEM ESTIMATES
- SUMMARY TEST FACILITY ESTIMATES

INTRODUCTION TO COSTS

This section presents aggregate cost estimates for the OTEC Test Facility and its various individual elements. The ground rules and assumptions on which these estimates are based are discussed first, followed by separate cost estimates of individual subsystems and programs. Combined estimates for various configurations of a complete Test Facility are given at the end of this section.

BASIS OF ESTIMATES

1. 1976 DOLLARS
2. ASSUMES NO USE OF EXISTING GOVERNMENT FACILITIES OR EQUIPMENT
3. LIFETIME PRESENT COST ESTIMATE:
 - CAPITAL COST + CAPITALIZED OPERATING COST = TOTAL COST
4. CAPITAL COST:
 - INCLUDES BUILDINGS, PIPES, STRUCTURES, EQUIPMENT
 - DOES NOT INCLUDE LAND ACQUISITION, COMPONENT TEST ARTICLES

BASIS OF ESTIMATES

All estimates are expressed in millions of mid-1976 dollars. It is assumed that all required equipment and facilities would be procured specifically for the project and that no use would be made of existing equipment and facilities.

The total cost estimates presented are composed of two elements: capital costs and capitalized operating costs. The capital cost estimates presented here are based on detailed estimates developed by Bechtel Corporation. They include the cost of all required test facility construction, outfitting, and equipment. They do not include the cost of land acquisition nor that of test articles required by other than cycle plant operation.

N-7
Operating cost estimates include four major expense categories: personnel, overhead and general and administrative, electric power, and contingency allowance. Personnel costs are estimated on the assumption that personnel required for test facility operation will be paid at current LMSC rates. For a 6 MW cycle plant, personnel costs are then allocated among cycle plant, component test, and advanced research and technology activities in a 3:2:1 ratio. Overhead and general and administrative expense is estimated for each activity on the basis of allocated man-hours, employing current LMSC rates.

It is assumed that electricity generated by the cycle plant will be available to power intake water pumps; however, this power supply may not be sufficient should large piping distances and/or elevations be required. In addition, turbine testing requires very large energy inputs that will have to be supplied by an outside source. Electric power costs beyond those included in the overhead charge are estimated on the assumption of a 30 mills/KWH charge rate. Finally, to cover unforeseen expenditure a contingency allowance of 15% of the sum of the above described expense categories is included in the total operating cost estimate.

BASIS OF ESTIMATES (CONCLUDED)

5. OPERATING COST

- ESTIMATED REQUIRED PERSONNEL APPORTIONED AMONG CYCLE PLANT, COMPONENT TEST, AND ADVANCED RESEARCH AND TECHNOLOGY IN 3:2:1 RATIO
- REPRESENTATIVE OVERHEAD AND GENERAL ADMINISTRATIVE RATES
- POWER COST BASED ON 30 MILLS/KWH; 6000 HRS/YR
CYCLE PLANT POWER OUTPUT ASSUMED AVAILABLE FOR PUMPS
- 15% CONTINGENCY ALLOWANCE
- COST CAPITALIZED OVER 10 YEARS; 10% DISCOUNT RATE
- DOES NOT INCLUDE OPERATOR'S FEE, COMPONENT TEST ARTICLES

BASIS OF ESTIMATES (CONTINUED)

Total yearly operating costs are capitalized over the expected test facility lifetime to provide a present cost estimate of total lifetime project cost. This capitalization is based on a 10% discount rate over a 10 year expected lifetime.

It should be noted that operating cost estimates do not cover the cost of test articles, nor the fee that would be charged by a private test facility operator.

SUBSYSTEM ESTIMATES

1. CYCLE PLANT
2. COMPONENT TEST PROGRAM
3. ADVANCED RESEARCH AND TECHNOLOGY PROGRAM
4. FACILITY SUPPORT

SUBSYSTEM ESTIMATES

Cost estimates are grouped under four headings: cycle plant, component test program, advanced research and technology program, and facility support. Estimates for each of these categories are presented below in the same order in which they are listed, followed by aggregated estimates for various complete test facility configurations.

The following abbreviations are used in these viewgraphs:

COMP - COMPONENT

FAC - FACILITY

CONT - CONTINGENCY

PERS - PERSONNEL

OH - OVERHEAD

G&A - GENERAL AND ADMINISTRATIVE

ES - ENGINEERING SERVICES

MODS - MODIFICATIONS

CWP - COLD WATER PIPE

PWR - POWER

EQUIP - EQUIPMENT

IN - INDOOR

OUT - OUTDOOR

MISC - MISCELLANEOUS

SUP - PLATFORM SUPPORT

CONS - PLATFORM CONSUMMABLES

CP - CYCLE PLANT

DEP - DEPLOYMENT

CYCLE PLANT ESTIMATES--INTRODUCTION

SITE INDEPENDENCE DIRECTIVE: CONSIDER SITE RELATED CONDITIONS

LAND-BASED CYCLE PLANT: SITE ADJACENT TO WATER

SITE DISTANT FROM WATER

SHORE-BASED CYCLE PLANT: EASY PIPE PLACEMENT SITE

DIFFICULT PIPE PLACEMENT SITE

SEA-BASED CYCLE PLANT

CYCLE PLANT ESTIMATES - INTRODUCTION

Estimates are presented below for land-based, shore-based, and sea-based cycle plants. Estimates for land and shore-based plants assume cantilever wall construction.

Following ERDA's directive, all cost estimates are non-site specific; however, actual capital and operating costs are clearly dependent on site location. To illustrate the magnitude of this dependence, two alternative cases are considered for land-based and shore-based cycle plants. Costs are estimated for two land-based cycle plant locations, one near and one distant from the water supply source. The sensitivity of shore-based cycle plant costs to cold water pipe placement conditions is investigated by estimating them under assumptions of high and low unit cost per linear foot of pipe. Estimates are presented for land and shore-based plants of 1, 3, 6, and 9 MW_e output, and for 3, 6, 9 and 15 MW_e output sea-based cycle plant.

In all cases, the corresponding viewgraph covers only summary cost estimates. Backup tables for these summaries will be found in the Appendix.

LAND BASED CYCLE PLANT COST - \$M

SELECTED CONFIGURATION - CANTILEVER WALL CONSTRUCTION

MW NET OUTPUT	ADJACENT TO WATER*			DISTANT FROM WATER**		
	CAPITAL	OPERATING	TOTAL	CAPITAL	OPERATING	TOTAL
1	25.3	8.6	33.9	28.9	11.2	40.1
3	36.6	13.6	50.2	46.5	24.1	70.6
6	57.9	17.1	75.0	76.7	33.3	115.0
9	76.6	19.6	96.2	100.1	51.3	151.4

*WATER SOURCES WITHIN 1000 FT OF PLANT; RESERVOIRS AT PLANT GRADE

**WATER SOURCES 5000 FT FROM PLANT; RESERVOIRS 100 FT BELOW PLANT GRADE

LAND-BASED CYCLE PLANT COST

In this case, two alternative locations are considered for a land-based cycle plant. The first site is located within 1000 feet of warm and cold water sources, and at grade with them. Plant output is then sufficient to power the pumps and operating costs consist simply of personnel costs; these were estimated as already discussed for a 6 MW plant, and scaled up or down in proportion to the cube root of plant output. Capitalized operating costs at such a site account for approximately a fifth of total cycle plant lifetime costs.

The second site considered is assumed to be 5000 feet distant from its water sources, and 100 feet above it. This requires extensive piping and increases in pump capacity, resulting in a 10% to 20% increase in capital costs; electric power purchases required by the accompanying increase in pumping requirements lead to operating cost increases ranging from 30% to 250%; total lifetime costs increase by between 20% and 50%. The increase in both cost categories increases with output, as water flow related cost components become a greater fraction of total cost.

SHORE BASED CYCLE PLANT COST - \$M

SELECTED CONFIGURATION - CANTILEVER WALL CONSTRUCTION

MW NET OUTPUT	EASY PIPE LAYING*			DIFFICULT PIPE LAYING**		
	CAPITAL	OPERATING	TOTAL	CAPITAL	OPERATING	TOTAL
1	37.0	8.6	45.6	49.0	8.6	57.6
3	57.3	13.6	70.9	78.0	13.6	91.6
5	98.8	17.1	115.9	116.5	17.1	133.6
9	112.2	19.6	131.8	147.7	19.6	167.3

*CWP COST IS 3000 \$/FT FOR 3 MW PLANT; 5000 FT LONG CWP

**CWP COST IS 6000 \$/FT FOR 3 MW PLANT; 5000 FT LONG CWP

SHORE-BASED CYCLE PLANT COST

In the first case considered here the shore-based cycle plant is assumed to require a 5000 foot long cold water pipe costing 3000 \$/ft for a 3 MW plant; unit cold water pipe cost for different output plants is assumed to vary with the square root of their output. The length and cost of the cold water pipe correspond to ideal site conditions. Cycle plant electric output being sufficient to supply pumping requirements, operating costs remain as in the land-based cycle plant situated near the water supply source. The cold water pipe required by shore-based installations increases capital costs by between 40% and 60%, increasing with output; total costs are roughly 35% higher than those of a land-based plant located near its water sources.

In the second case, the cost of cold water pipe placement is assumed to be 6000 \$/ft for a 3 MW plant; the length of the pipe is again assumed to be 5000 feet. While the placement unit cost represents a worst-case situation, the assumed pipe length still corresponds to rather favorable (steep) site conditions. Operating costs are the same as in the previous case, but higher cold water pipe costs result in increases of roughly 80% and 70%, respectively, in capital and total life cycle present costs.

SEA BASED CYCLE PLANT COST - \$M

MW NET OUTPUT	BARGE			TANKER			SEMI-SUBMERSIBLE		
	CAPITAL	OPERATING	TOTAL	CAPITAL	OPERATING	TOTAL	CAPITAL	OPERATING	TOTAL
3	16.8	40.6	57.4	23.8	40.6	64.4	61.7	40.6	102.3
6	27.6	46.1	73.7	34.1	46.1	80.2	71.8	46.1	117.9
9	37.8	50.4	88.2	44.2	50.4	94.6	81.6	50.4	132.0
15	55.9	55.4	111.3	61.7	55.4	117.1	98.8	55.4	154.2

* NO SW PUMP OR CWP DEPLOYMENT TEST CAPABILITY

SEA-BASED CYCLE PLANT COST

Three alternative types of cycle plant carrier are considered: a barge, a tanker, and a semisubmersible. Estimated operating costs are the same in all cases. A barge-borne cycle plant is the least expensive alternative, costing approximately 10% less than a tanker-borne plant; semisubmersible-borne cycle plants require a capital outlay two to three times greater than those associated with other alternatives. Capitalized operating costs account for roughly half of total costs for barge- and tanker-borne plants, and for approximately a third of total cost of semisubmersible-borne plants.

6 MW CYCLE PLANT COST COMPARISON

6 MW CYCLE PLANT COST COMPARISON

The accompanying chart presents a total cost comparison of various land, shore, and sea-based cycle plants of identical output. Shore-based plants are in all cases more costly than favorably sited land-based plants. Indeed, an unfavorably sited land-based cycle plant is equally expensive as a favorably sited shore-based plant. Unfavorably sited shore-based plants are the most expensive alternatives considered.

By comparison with land-based cycle plants of similar output, barge- and tanker-borne sea-based plants require smaller capital outlays and greater operating outlays; the total costs of these types of sea-based cycle plant are comparable to those of land-based plants situated near warm and cold water sources. The total cost of a semisubmersible-borne cycle plant is roughly equal to that of a land-based plant situated far from water sources.

AT-SEA TEST PLATFORM

CAPITAL COST - \$M

T-2	T-2 MODS	CP EQUIP	SW PUMP TEST	CWP DEP TEST	CONT	ES	TOTAL
7.0	4.1	15.7	2.3	0.6	6.8	4.5	41.0

OPERATING COST - \$M

PERS	OH	G&A	CREW	SUP	CONS	CONT	TOTAL
1.5	1.5	0.5	1.9	1.0	0.5	1.1	8.1

● CAPITALIZED OPERATING COST: \$49.8 M

AT-SEA TEST PLATFORM

The sea-based cycle plants for which cost estimates were previously presented did not include capability for either sea water pump or cold water pipe deployment testing. In order to estimate with any accuracy the cost of providing these testing capabilities, it is necessary to further define platform characteristics. For this reason, the accompanying estimate of an at-sea facility including a 6-MW cycle plant and full-scale sea water pump and cold water pipe deployment test installations is presented using a T-2 tanker as being representative of test platforms. Its total lifetime cost is approximately \$10.6 million more than that of a 6-MW tanker-borne cycle plant.

COMPONENT TEST COST - \$M

TOTAL COST

	CAPITAL			OPERATING	TOTAL
	HX TEST	TURBINE TEST	HYD TEST		
CASE A*	9.7	22.8	2.3	24.6	59.4
CASE B**	9.7	22.8	2.3	28.9	63.7

YEARLY OPERATING COST

	PER'S	OH	G&A	SUPPLIES	PWR	CONT	TOTAL
CASE A*	0.7	0.7	0.2	0.1	1.8	0.5	4.0
CASE B**	0.9	1.0	0.3	0.1	1.8	0.6	4.7

*COMBINED CYCLE PLANT - COMPONENT TEST FACILITY

**SEPARATE CYCLE PLANT AND COMPONENT TEST FACILITIES

COMPONENT TEST COST

Detailed capital cost estimates will be found in the Appendix for component test facilities capable of accommodating 0.25 and 2.5 MW heat exchangers, 1/16, 1/4, and full-scale turbines, and 1/50-scale hydrodynamic models. The accompanying viewgraph shows the estimated cost of a combined facility for testing 0.25-MW heat exchangers, all scales of turbines, and hydrodynamic models. This particular facility configuration was selected solely for illustrative purposes. The capital cost of any alternative configuration can be calculated by summing the costs of the individual component test installations presented in the Appendix; for example, the capital cost of a facility capable only of testing 2.5-MW heat exchangers and 1/16 scale turbines is \$29.0 million.

The magnitude of the operating costs of the component test program depends on whether it is conducted in a combined cycle plant-component test facility or in a separate component test installation. In the first case advantage can be taken of personnel commonality, resulting in a yearly cost of \$4 million; in the second, the total yearly cost is \$4.7 million.

In both cases a \$1.8 million allowance is included for electric power purchases required for the component test program, reflecting a requirement of 10 MW over a duty cycle of 6000 hours per year. This electricity consumption is estimated on the assumption that the average turbine test requirement will be roughly 9 MW, i. e., that of a 1/4-scale test. Should full-scale turbine testing be performed 6000 hours per year, required electricity purchases would cost approximately \$6.0 million per year.

ADVANCED RESEARCH & TECHNOLOGY COST — \$M

YEARLY OPERATING COST

	PERS	OH	G&A	SUPPLIES	CONT.	TOTAL
CASE A*	0.3	0.4	0.1	0.1	0.1	1.0
CASE B**	0.5	0.5	0.1	0.1	0.1	1.3

- CASE A* CAPITALIZED OPERATING COST: \$6.0M
- CASE B** CAPITALIZED OPERATING COST: \$8.0 M
- NO ASSOCIATED CAPITAL COSTS

*COMBINED CYCLE PLANT – COMPONENT TEST FACILITY

**SEPARATE CYCLE PLANT AND COMPONENT TEST FACILITIES

ADVANCED RESEARCH AND TECHNOLOGY COST

As was the case with the component test program, the operating cost of the Advanced Research and Technology program depends on whether cycle plant, component test, and Advanced Research and Technology activities are carried out in combined or in separate facilities. In the first case, the annual operating cost of the Advanced Research and Technology program is approximately one million dollars; the corresponding capitalized present cost is approximately six million dollars. When cycle plant facilities are located separately, Advanced Research and Technology operating costs are approximately one third higher.

The bulk of the figures quoted above represents personnel costs, although allowances are included for miscellaneous test supplies. No major capital costs are associated with the Advanced Research and Technology program, as relevant activities will be conducted within facilities already accounted for as part of component test capital costs.

LAND BASED TEST FACILITY SUPPORT COST - \$M

CAPITAL COST

DATA SYSTEM			CONSTRUCTION			MISC EQUIPMENT			TOTAL
EQUIP	PERS	CONT	FIELD	CONT	ES	IN	OUT	CONT	14.5
1.1	1.1	0.3	6.4	1.6	1.0	1.7	1.0	0.3	

- OPERATING COST INCLUDED IN OVERHEAD AND
GENERAL & ADMINISTRATIVE ALLOWANCES

LAND-BASED TEST FACILITY SUPPORT

The capital cost of test facility support installations is 14.5 million dollars, for a complex including a land- or shore-based cycle plant and installations for component test and Advanced Research and Technology activities. This total includes construction, data processing equipment and hardware and software development, and miscellaneous equipment costs, all previously presented in detail. No operating costs are explicitly associated with facility support, as it is included in the allowances for overhead and general and administrative expense already applied to cycle plant, component test, and Advanced Research and Technology activities.

The data acquisition and control system included in this estimate covers central data processing hardware and input/output facilities located at the cycle plant and at four test areas. An alternative system, providing such facilities for eight test areas in addition to the cycle plant, would cost approximately 3.3 million dollars; total facility support cost would then be 15.3 million dollars.

SEA BASED TEST FACILITY SUPPORT COST - \$M

CAPITAL COST

	DATA SYSTEM			CONSTRUCTION			MISC EQUIPMENT			TOTAL
	EQUIP	PERS	CONT	FIELD	CONT	ES	IN	OUT	CONT	
CASE B1*	1.5	1.1	0.4	6.5	1.6	1.0	1.9	1.3	0.3	15.6
CASE B2**	1.5	1.1	0.4	8.1	2.0	1.2	2.7	2.0	0.7	19.7

- OPERATING COST INCLUDED IN OVERHEAD AND GENERAL & ADMINISTRATIVE ALLOWANCES

*LAND TEST AT SHORE FACILITY

**LAND TEST SEPARATE FROM SHORE FACILITY

SEA-BASED TEST FACILITY SUPPORT COST

In this case, the cost of test facility support equipment and installations depends on whether component test and Advanced Research and Technology activities take place at a shore facility which also supports the sea-based cycle plant, or at a separate facility. In the second case, unavoidable function and equipment duplication will result in higher construction and miscellaneous equipment costs. However, the data acquisition and control system cost is the same in both cases.

Both land- and sea-based test facility support costs have been estimated on the assumption that they are independent of cycle plant size. While this is not strictly correct, it seems a reasonable approximation given the conceptual nature of the estimates presented here.

LAND BASED TEST FACILITY COST SUMMARY - \$M

MW	CYCLE PLANT*		CCOMPONENT TEST		AR&T	SUPPORT	TEST FACILITY		
	CAPITAL	OPERATING	CAPITAL	OPERATING	OPERATING	CAPITAL	CAPITAL	OPERATING	TOTAL
1	25.3	8.6	34.8	24.6	6.0	14.5	74.6	39.2	113.8
3	36.6	13.6	34.8	24.6	6.0	14.5	85.9	44.2	130.1
6	57.9	17.1	34.8	24.6	6.0	14.5	107.2	47.7	154.9
9	76.6	19.6	39.8	24.5	6.0	14.5	125.9	50.2	176.1

*SELECTED CONFIGURATION, SITE ADJACENT TO WATER

LAND-BASED TEST FACILITY COST SUMMARY

The accompanying viewgraph presents a summary of the major cost components in a land-based test facility located adjacent to warm and cold water sources, and including component test facilities for 0.25-MW heat exchangers, a full range of turbine scales, and 1/50-scale hydrodynamic models. A similar summary can easily be prepared for locations more distant from water sources by changing the relevant cost components. The information presented in this table can be summarized as follows:

- (1) Test facility total cost increases by roughly 50% as cycle plant output increases ninefold.
- (2) Capital costs account for roughly 70% of total costs.
- (3) Cycle plant costs increase in importance from 30% to 60% of total costs as output increases from 1 to 9 MW.
- (4) At the same time, the proportion of total costs accounted for by component test costs decreases from one half to one third.

SHORE BASED TEST FACILITY COST SUMMARY - \$M

MW	CYCLE PLANT*		COMPONENT TEST		AR&T	SUPPORT	TEST FACILITY		
	CAPITAL	OPERATING	CAPITAL	OPERATING	OPERATING	CAPITAL	CAPITAL	OPERATING	TOTAL
1	37.0	8.6	34.8	24.6	6.0	14.5	86.3	39.2	125.5
3	57.3	13.6	34.8	24.6	6.0	14.5	106.6	44.2	150.8
6	98.8	17.1	34.8	24.6	6.0	14.5	148.1	47.7	195.8
9	112.2	19.6	34.8	24.6	6.0	14.5	161.5	50.2	211.7

*SELECTED CONFIGURATION, EASY PIPE PLACEMENT SITE.

SHORE-BASED TEST FACILITY COST SUMMARY

The total cost of a shore-based test facility is shown for the case in which the site selected presents favorable pipe laying conditions, so that the 5000 foot cycle plant cold water pipe can be held to a unit cost of 3000 \$/ft. Component Test facilities are identical to those included in the land based test facility. The main features of this cost summary are as follows:

- (1) Test facility total cost is approximately doubled as cycle plant output is increased by a factor of nine.
- (2) Capital costs are now somewhat more important than in a land-based test facility, accounting for more than three quarters of total costs.
- (3) Cycle plant costs increase with increasing output from 35% to 55% of total facility costs, while component test costs decrease from less than half to less than 30% of total costs.

SEA BASED TEST FACILITY COST SUMMARY - \$M

	CYCLE PLANT*		COMPONENT TEST**		AR&T**	SUP- PORT**	TEST FACILITY ^v		
	CAPITAL	OPERATING	CAPITAL	OPERATING	OPERATING	CAPITAL	CAPITAL	OPERATING	TOTAL
3	23.8	40.6	34.8	24.6	6.0	15.6	74.2	71.2	145.4
6	34.1	46.1	34.8	24.6	6.0	15.6	84.5	76.7	161.2
9	44.2	50.4	34.8	24.6	6.0	15.6	94.6	81.0	175.6
15	61.7	55.4	34.8	24.6	6.0	15.6	112.1	86.0	198.1

*TANKER-BORNE

**COMBINED CYCLE PLANT - COMPONENT TEST FACILITY

SEA-BASED TEST FACILITY COST SUMMARY

The total cost of a sea-based test facility is shown in the accompanying viewgraph, under the assumption that component test activities are carried out in a shore facility. Component test facilities are similar to those in the land and shore based test facilities; no seawater pump or cold water pipe deployment test capability is included. The main observations arising from this table are as follows:

- (1) Total facility cost increases by approximately one quarter as cycle plant output increases fivefold.
- (2) Capital costs now account only for roughly half of total costs.
- (3) Cycle plant costs now range from 40% to 50% of total facility costs; component test costs range from 40% to 30% of total costs.

6 MW TEST FACILITY COST COMPARISON

*SELECTED CONFIGURATION

**COMBINED CYCLE PLANT-COMPONENT TEST FACILITY

6 MW_e TEST FACILITY COST COMPARISON

Comparison of the costs of the three test facility configurations discussed earlier shows that land- and sea-based test facilities have similar total costs for similar cycle plant outputs, while the shore-based test facility costs approximately 20% more than either. The difference in the ratio of capital to operating cost between sea based facilities and land or shore-based facilities is noteworthy.

SCHEDULES

PRESENTED BY
MURRAY I. LEITNER

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

SCHEDULES

Relative risk schedule

OTEC program progression and milestones

RELATIVE RISK SCHEDULE

RELATIVE RISK SCHEDULES

Four "Relative Risk Schedules" were compared in order to arrive at a reasonable cost/risk/time span approach toward the objective of a demonstration plant. The "Maximum Risk" schedule is directed toward the Demonstration Plant with no intermediate activities. Using "state-of-the-practice," this Demonstration Plan would provide at least 60% of the baseline performance and would be available by 1983.

The "High Risk" approach includes Engineering Development and AR&T and a Cycle Plant (sea-based) prior to the Demonstration Plant effort. This plant would be available by 1985 and should provide at least 80% of the baseline performance.

The "Moderate Risk" approach adds Component Development tests and a Pilot Plant having a full scale module. The costs shown reflect incorporation of this module into the Demonstration Plant. With this approach, the Demonstration Plant should be available before the end of 1987 and should provide at least 90% of the baseline performance.

The "Low Risk" approach incorporates the same five phases but the work is done sequentially so that initial test results are available prior to initiating the next phase. This extends the program such that the Demonstration Plan will not be available until 1992. This plant should provide 95% of the baseline performance.

The "Moderate Risk" approach has been selected for this program.

OTEC PROGRAM PROGRESSION & MILESTONES

OTEC PROGRAM PROGRESSION & MILESTONES

The schedule shown carries the program to the test portion of the demonstration plant efforts. This schedule is conservative in that it allows for the preparation, release, and response to an RFP with an award at the end of the first quarter of 1977. At that point, AR&T investigations are initiated and preliminary efforts started on the site requirements for the component and cycle plant test facilities. With no acceleration in the construction efforts, the component test facility will be operational during the last quarter of 1980 and the cycle plant will be ready for start-up in the first quarter of 1982.

It is anticipated that 6 months of cycle plant testing would be obtained prior to receiving authorization to proceed with the sea-based pilot plant. Authorization to proceed with the demonstration plant should be obtained following successful demonstration of the pilot plant. However, in order to proceed with the fabrication of the pilot plant or the full-scale demonstration plant, it is necessary to initiate the manufacturing facilities for each at an adequate time span ahead of the authorization dates shown.

The Early Ocean Test Platform (EOTP) effort may be considered as a separate program within the overall OTEC program. Go-ahead on the EOTP effort should be provided by the last quarter of 1976 in order to meet the departure date of November 1, 1978 with minimum risk.

The feedback from the various test phases is used to modify the OTEC system design and performance specifications as they progress from preliminary through the interim stage to the final documentation.

CONCLUSIONS

PRESENTED BY
ROGER D. FULLER

CONCLUSIONS

- ENGINEERING DEVELOPMENT AND AR&T SHOULD BEGIN IMMEDIATELY
- COMPONENT TEST FACILITIES SHOULD HAVE CAPABILITY TO TEST:
 - HEAT EXCHANGERS UP TO 10^5 BTU / SEC THERMAL CAPACITY
 - 1 / 5 LINEAR SCALE AMMONIA TURBINES
- CYCLE PLANT SHOULD BE SEA-BASED WITH 6-MWe CAPABILITY

CONCLUSIONS

The desirability of evaluating concepts, which could lead to improved performance and reduced costs, in a timely manner for incorporation into future components suggests that Engineering Development and AR&T efforts be initiated immediately utilizing the qualified government, institution and contractor laboratories. For future generation hardware, a laboratory which could support AR&T as well as other activities, such as component diagnostics, could be part of the ERDA/OTEC test facilities.

P-3 Existing contractor/vendor facilities reviewed cannot accommodate the full scale or moderately scaled key power cycle components. Data shown in Section E indicates that rotating machinery performance can be predicted from 1/5 linear scale model testing. However, industrial experience with ammonia turbines is very limited. Therefore, it is concluded that facilities should be provided for the testing of heat exchangers and ammonia turbines. The former should be sized to accommodate exchangers with thermal capacities up to 10^5 BTU/sec and the latter capable of testing 1/5 linear scale turbines using ammonia. Steam or air as the driving media should be evaluated in the near future in order to determine the need to conduct future turbine AR&T and component testing with ammonia.

The results of the cycle plant investigations suggest an at-sea facility, 6 mW_e net capability, to provide data on component interactions, off-design performance, operational and maintenance procedures. This approach may permit usage of scaled rotating machinery previously used in component development testing; is not limited by thermal resources; and provides the confidence to proceed to the full scale pilot plant module.

OTEC PROGRAM- CONCEPTUAL SCHEDULE

OTEC PROGRAM -- CONCEPTUAL SCHEDULE

The stated purpose of the OTEC Test Facilities Study Program was to develop information and data on alternative test facility requirements (cost, schedule, and performance) to such depth as needed by ERDA for Test Facility planning. The conceptual schedule shown is one which incorporates the various test phases and facilities (land-based, sea-based, system, component, and AR&T) but as stated above, the conclusion as to which test phase or facility is planned or acquired is left to ERDA.

The conceptual schedule presented is an advancement of the "moderate risk" program schedule shown in Section O. The Engineering Development and AR&T efforts should begin immediately and, in fact, present investigations in heat transfer enhancement should be considered as part of this program.

The Major Component test facilities are primarily for scaled heat exchangers and turbines which incorporate advances resulting from AR&T efforts. The Cycle Plant is sea-based with the initial configuration incorporating "state-of-the-art" components. Future generation hardware, resulting from component test efforts, will be incorporated as they develop.

Authorization to proceed with the sea-based Pilot Plant is scheduled six months after the start of Cycle Plant testing. However, in order to meet the schedule shown, it is necessary to initiate the fabrication facility at an adequate time span ahead of the authorization data shown.

The Early Ocean Test Platform (EOTP) is considered to be outside the purview of the present contract. However, its temporal relationship to the conceptual schedule for test facilities is shown to indicate how the test results can be integrated into the Cycle Plant configuration.