

A RAND NOTE

PROJECTED ENGINEERING COST ESTIMATES FOR
AN OCEAN THERMAL ENERGY CONVERSION (OTEC)
CENTRAL STATION

E. C. Gritton, R. W. Hess, R. Y. Pei

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PREFACE

Rand has developed a methodology for studying the cost sensitivities and engineering uncertainties of advanced energy conversion systems. The methodology has been successfully applied to an evaluation of the ocean thermal energy conversion (OTEC) technology. The complete analysis and results of this evaluation are reported in Rand report R-2595-DOE, an executive summary of which is published in a companion Rand report, R-2641-DOE.

The study results were favorably received by the OTEC community and interest was expressed in applying the Rand methodology to estimate the potential cost reductions that might be achieved if certain improvements could be realized in the engineering, construction, and financing of the OTEC system. The results of this Rand-sponsored analysis are documented in this Note. The study results were also presented in a technical paper at the 8th Annual Ocean Energy Conference held in Washington, D.C., on June 9, 1981.

SUMMARY

This Note summarizes an investigation into the potential cost reductions that might be achieved if certain engineering, construction, and financial improvements were realized in the OTEC concept. Six options have been analyzed: water-side heat transfer enhancement (for tube-and-shell heat exchangers), plate-type heat exchangers, fiberglass-reinforced-plastic (FRP) cold-water pipes, elimination of the requirement that the transmission cable be buried at ocean depths of less than 300 feet, a shorter construction period, and a reduced fixed charge rate. It was found that the changes having the most effect on capital cost are the two heat exchanger options and the shorter construction period. However, to achieve major reductions in capital cost, say on the order of 30 percent, a combination of one of the heat exchanger options in conjunction with the cold-water pipe, transmission cable, and construction period options will be required.

Two applications were considered for the islands of Puerto Rico and Hawaii: an offshore OTEC platform similar to the reference case configuration and an onshore installation with the necessary cold-water pipe and site acquisition. The results indicate that the advantages of onshore installations, as compared with offshore platforms, lie more in the lessening of technological risks and the lowering of operations and maintenance costs than in any dramatic reduction of system costs.

Finally, the projected engineering cost estimates were compared with costs of coal-fired and nuclear plants. For OTEC to be competitive, there will have to be significant real growth in the fuel costs and/or construction costs of conventional coal-fired and nuclear plants.

CONTENTS

PREFACE	iii
SUMMARY	v
FIGURES	ix
Section	
I. INTRODUCTION	1
II. SYSTEM RELIABILITY	4
III. COST REDUCTION ALTERNATIVES	5
IV. COMPARISON OF OFFSHORE AND ONSHORE PLANT COSTS	7
V. COMPARISON WITH COAL-FIRED AND NUCLEAR-FUELED PLANTS	9
VI. CONCLUSIONS	11
REFERENCES	13

FIGURES

1.	OTEC engineering and performance cost model	2
2.	Distribution of reference case capital costs (1978\$)	3
3.	Effect of system reliability on cost of electricity	4
4.	Cost reduction alternatives	6
5.	Island site: Puerto Rico	8
6.	Island site: Hawaii	8
7.	Breakeven OTEC capital cost as a function of the annual real rate of fuel cost increase	10
8.	Breakeven OTEC capital cost as a function of the annual real rate of capital cost growth in coal and nuclear plants	10

I. INTRODUCTION

This Note examines the potential for reducing ocean thermal energy conversion (OTEC) costs through improvements in engineering, construction, and financing. A first-order comparison of OTEC system costs with coal-fired and nuclear power plants is also made.[1] We found in other Rand studies of advanced energy technology systems that early cost estimates are usually optimistic and that the total integrated systems approach must be used to develop meaningful estimates of both the capital costs and the cost of electricity. We also found that there are areas of potential technological advances which, if realized, might reduce the total system cost. This paper evaluates the potential cost reductions for several OTEC technology advances. To obtain projected engineering cost estimates, we used our OTEC engineering performance and cost model (see Fig. 1).

To provide meaningful comparisons, it was first necessary to establish a reference case. The derivation of this reference case is described in more detail in Ref. 1. Key assumptions upon which the reference case is based include:

- o Closed-cycle OTEC system.
- o Central station, commercial scale (240-400 MWe) application with all power cabled to shore.
- o Site: Gulf of Mexico.
- o All estimates are in constant 1978 dollars.[2]

[1] For a quantitative evaluation, baseline cost estimates, and sensitivity analysis, see Ref. 1.

[2] To obtain a reasonable estimate of costs in 1980 dollars, multiply by 1.2 (the 1978-1980 escalation factor given by the Chemical Engineering Plant Index).

OTEC ENGINEERING PERFORMANCE AND COST MODEL

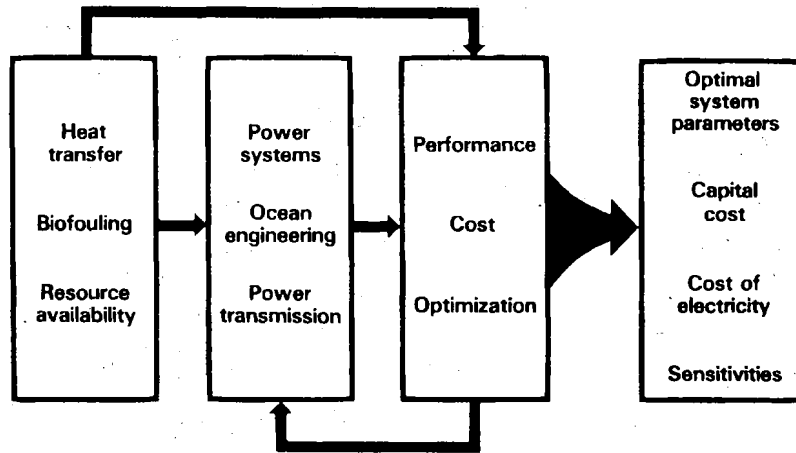


Fig. 1 -- OTEC engineering and performance cost model

- o The Electric Power Research Institute (EPRI) methodology was used to compute the cost of electricity.[Ref. 3]
- o No financial incentives such as ship-building subsidies or tax preferences were considered.

The distribution of capital costs for our reference case is presented in Fig. 2. It is based on a system located off the coast of Tampa, Florida, with a capacity of 400 MWe. It has a concrete barge-type platform and a steel cold-water pipe. The heat exchanger is a tube-and-shell type manufactured of titanium. We assumed a construction period of five years and a fixed charge rate of 18 percent. The resultant cost of electricity is:

	<u>mills/kwh</u>
Capital	89
Operations & Maintenance (O&M)	7
Total	<u>96</u>

DISTRIBUTION OF CAPITAL COST (1978 \$) 400 MWe

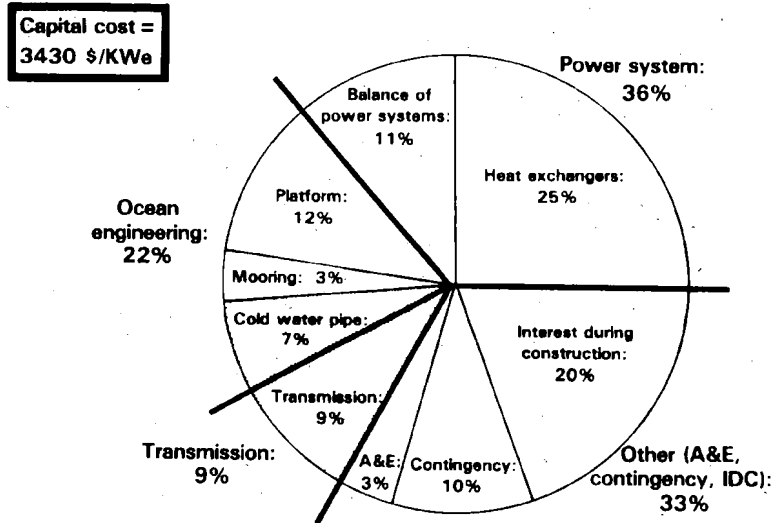


Fig. 2 -- Distribution of reference case capital costs (1978\$)

II. SYSTEM RELIABILITY

Before discussing the cost reduction options, it is worthwhile to first emphasize the critical nature of a factor which is frequently overlooked in a technology's concept formulation stage--system reliability. The reference case assumed a reliability factor of .90. However, as illustrated in Fig. 3, the cost of electricity is extremely sensitive to this assumption. Within the range shown, each percentage point increase in downtime results in an increase in the cost of electricity on the order of 1 to 2 mills per kwh. Note that downtime includes both scheduled and unscheduled maintenance but does not account for any effect due to seasonal variation.

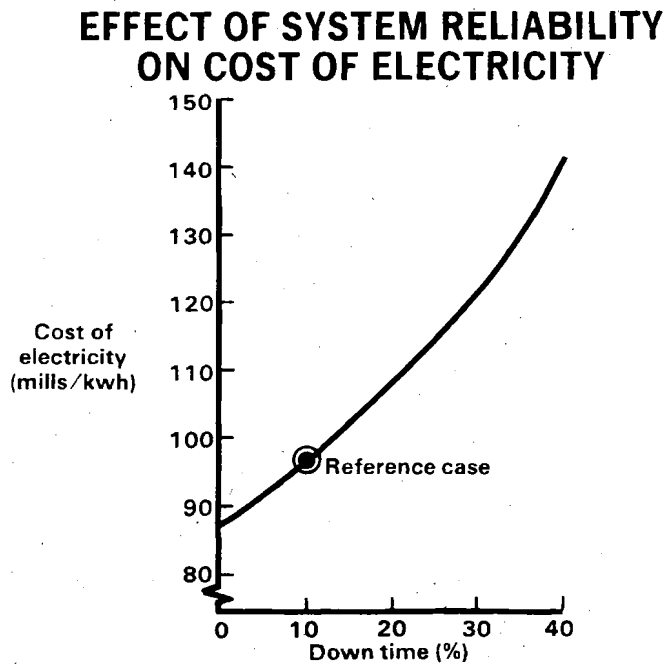


Fig. 3 -- Effect of system reliability on cost of electricity

III. COST REDUCTION ALTERNATIVES

Seven alternatives for cost reduction were considered, as shown in Fig. 4. Each of the first six contains one variation from the reference case (or Rand base case), whereas the last case combines five of the alternatives (an optimistic case). [1] The cost of producing roughened tube surfaces for water-side heat transfer enhancement is estimated on the basis of an analogue to Union Carbide's "Linde" process. The plate-type heat exchanger (HX) estimate is based on information provided by the Lockheed Missile and Space Company for the Alpha Laval heat exchanger.

The feasibility of options D, E, and F is subject to some uncertainty. The elimination of the requirement that the transmission cable be buried at depths of less than 300 feet may be theoretically possible but the practicality of establishing a stay-away zone is in question. Furthermore, the means by which the length of the construction period would be reduced from five years to two years and the fixed charge rate from 18 to 15 percent are not addressed in this analysis.

Figure 4 presents the projected system costs of these alternative configurations for a Gulf of Mexico application. The heat exchanger modifications and the shorter construction period appear to have by far the most significant impact on reducing total system capital cost. A three percentage point reduction in the fixed charge rate will lower the cost of electricity (COE) by 16 percent.

[1] The water-side heat transfer enhancement and the plate heat exchanger options are mutually exclusive; hence, only five of the six options are combined.

ALTERNATIVES

	Capital cost		COE	
	\$ / kWe	%Δ	Mills/kwh	%Δ
Reference case	3430	—	96	—
A Water-side heat transfer enhancement	3140	-8	88	-8
B Plate HX (from tube and shell)	2930	-15	86	-10
C FRP cold water pipe (from steel)	3260	-5	92	-4
D No cable embedment (from 85 mm to 0)	3290	-4	92	-4
E Construction period (5 years to 2)	3030	-12	86	-10
F Fixed charge rate (18% to 15%)	3430	0	81	-16
G Options B, C, D, E, & F combined	2350	-31	60	-38

Filtered

Fig. 4 -- Cost reduction alternatives

IV. COMPARISON OF OFFSHORE AND ONSHORE PLANT COSTS

Figures 5 and 6 show the capital costs by subsystem and cost of electricity for two approaches to an island application: (1) an offshore platform similar to the reference case configuration, and (2) an onshore installation with the necessary cold-water pipe and site acquisition. These estimates are compared with the reference case.

The thickness of the cold-water pipe is assumed to be the same for both platform and onshore applications. The increase in power system costs for the onshore application results from the increased pump power requirement, which in turn means larger heat exchangers. System costs for the onshore installation in Puerto Rico are essentially equivalent to offshore platform costs (Fig. 5); for Hawaii (Fig. 6), the onshore installation is projected to cost approximately 10 percent less than the offshore platform. We find that the effect of cold-water pipe (CWP) costs is not significant. Even with a two- or three-fold increase in the CWP cost, the total system cost differences between onshore and platform applications of OTEC systems are not dramatic. However, there are other considerations:

- a. Shore stations do not require advanced underwater transmission cable or deep-water mooring technologies.
- b. Shore stations are likely to have higher system availability and lower operating and maintenance costs which are not reflected in the above estimates.

ISLAND SITE: PUERTO RICO

	Reference case <u>Tampa</u>	Offshore platform <u>Puerto Rico</u>	Onshore <u>Puerto Rico</u>
<u>Capital cost by subsystem</u>			
Site acquisition, improve- ments, buildings	0	0	120
Power system	1235	1235	1332
Ocean engineering			
Platform	408	407	0
Cold water pipe	214	206	628
Mooring	115	47	0
Discharge pipes	(a)	(a)	63
Transmission	328	36	0
Other	<u>1130</u>	<u>939</u>	<u>735</u>
TOTAL	3430	2870	2878
<u>Cost of electricity</u>			
Capital	89	70	70
O&M	<u>7</u>	<u>7</u>	<u>7</u>
TOTAL	96	77	77

^aIncluded in platform

Fig. 5 -- Island site: Puerto Rico

ISLAND SITE: HAWAII

	Reference case <u>Tampa</u>	Offshore platform <u>Hawaii</u>	Onshore <u>Hawaii</u>
<u>Capital cost by subsystem</u>			
Site acquisition, improve- ments, buildings	0	0	120
Power system	1235	1235	1285
Ocean engineering			
Platform	408	407	0
Cold water pipe	214	165	314
Mooring	115	37	0
Discharge pipes	(a)	(a)	61
Transmission	328	35	0
Other	<u>1130</u>	<u>911</u>	<u>578</u>
TOTAL	3430	2790	2358
<u>Cost of electricity</u>			
Capital	89	76	64
O&M	<u>7</u>	<u>7</u>	<u>7</u>
TOTAL	96	83	71

^aIncluded in platform

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Fig. 6 -- Island site: Hawaii

V. COMPARISON WITH COAL-FIRED AND NUCLEAR-FUELED PLANTS

The impact of fuel and plant construction cost increases is illustrated in Figs. 7 and 8. OTEC is a solar technology with a zero fuel cost. In Fig. 7 we use the potential annual real rate of fuel cost growth for alternative fuel-burning systems as a measure for comparing OTEC with other systems. We assumed a start of operations in the year 2000 and calculated the total cost of producing electricity for the next 30 years. We then calculated what the capital cost of OTEC would have to be in the year 2000 (in 1978 dollars) to produce electricity for the same total cost over the same 30 year time period. This is the break-even OTEC capital cost. Thus, a 2.5 percent growth rate in fuel cost will make OTEC competitive with a coal-fired plant; for OTEC to be competitive with a nuclear power plant, it will take more than a 4 percent growth rate in fuel cost. A detailed description of the methodology used in making these comparisons can be found in Ref. 2. In Fig. 8, we assumed no real growth of fuel costs but instead used the potential annual real rate of growth of alternative plant construction costs as a measure for comparison.

INCREASING FUEL COSTS MAKE OTEC MORE COMPETITIVE

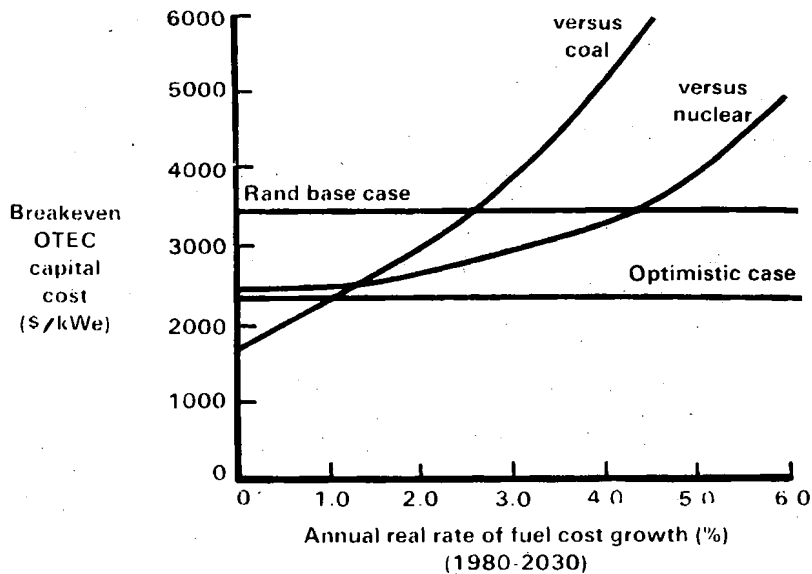


Fig. 7 -- Breakeven OTEC capital cost as a function of the annual real rate of fuel cost increase

INCREASING COAL AND NUCLEAR CAPITAL COSTS MAKE OTEC MORE COMPETITIVE

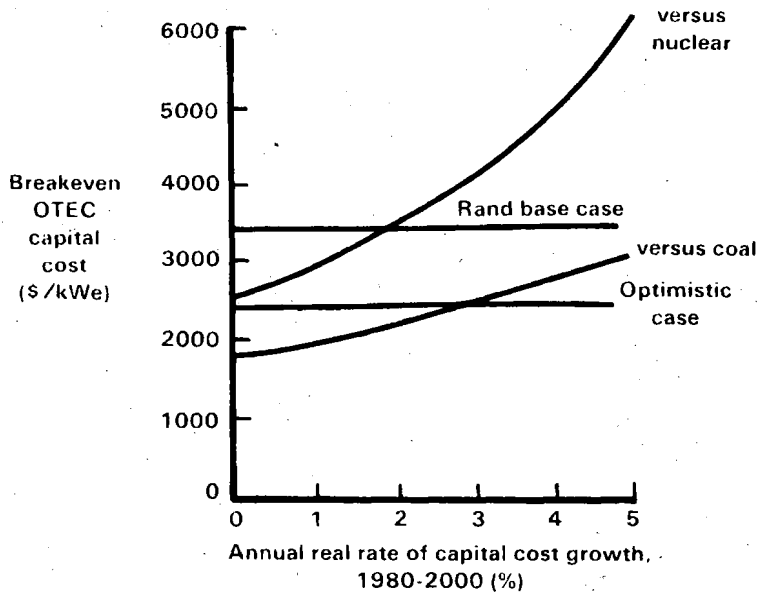


Fig. 8 -- Breakeven OTEC capital cost as a function of the annual real rate of capital cost growth in coal and nuclear plants

VI. CONCLUSIONS

There are a number of potential engineering and construction improvements which could lead to reductions in OTEC capital costs and cost of electricity. Among the several alternatives considered, savings resulting from changes in heat exchanger design (e.g., plate-type instead of the conventional tube-and-shell) or from enhancing the water-side heat transfer mechanism appear to be most significant. Among the island applications considered, the advantages of onshore installations over offshore platforms appear to lie more in the lessening of technological risks (e.g., the elimination of underwater transmission cable and deep-water mooring technologies) and the lowering of operations and maintenance costs, rather than in any dramatic reduction of system costs. Finally, for OTEC to be competitive with conventional coal-burning and nuclear power plants, there have to be significant real growths in fuel costs and/or construction costs of conventional coal and nuclear plants.

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