# OCEAN THERMAL ENERGY CONVERSION PROSPECTS FOR NEAR TERM DEVELOPMENT

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## ABSTRACT

Ocean Thermal Energy Conversion (OTEC) may be the most promising future electrical energy source for many nations located between 20°N and 20°S latitudes. Within this band are found the optimum physical conditions for OTEC development. Near-shore and land-based OTEC plant designs are underway for a number of island nations. Several governments in this region have declared OTEC to be the preferred alternative to their existing fossil fueled power plants, the fuel for which is imported at a severe economic penalty. OTEC by-products including fresh water, mariculture and cooling water are also of high interest in these arid, tropical sites. This paper reviews the factors that have lead to the recent interest in OTEC development.

## 1. INTRODUCTION

The initial step in evaluating the applicability of an energy technology is the preparation of a comprehensive and site specific energy assessment. A review of previously published assessments for the United States insular areas (Puerto Rico, United States Virgin Islands, Guam, American Somoa, the Northern Marianas and the Trust Territory of the Pacific Islands) indicates a leading candidate energy technology is OTEC[1]. A guide for developing countries to use in evaluating their energy needs is being prepared by the United Nations.

The next level in evaluating OTEC as a candidate energy technology is the preparation of an oceanographic and environmental assessment. With a conceptual OTEC plant design in mind, a siting investigation is undertaken which assembles the data on the thermal resource (and its variability) and on the oceanographic conditions necessary to evaluate all environmental impacts.

Finally, detailed economic analyses, designs (conceptual, preliminary and final), environmental and safety licenses and permits, construction, testing and operations would proceed in that order. Through the following discussion of known programs, a picture of the near term commercial reality of OTEC will emerge.

## 2. OTEC DESCRIPTION

OTEC uses the temperature differential (an example is given in Figure 1) between warm surface and cold deep ocean waters to produce electric power. This power is then either transmitted to shore via submarine cable or used for on-board production of transportable fuels or energy intensive industrial products. Two basic power systems have been proposed. In the closed cycle concept, a secondary working fluid (e.g., ammonia) is vaporized and recondensed in a closed loop to drive a turbine. The working fluid is vaporized by warm water that is drawn from the surface and passed through heat exchangers. This working fluid expands, emerging as a high pressure steam which drives a turbine. The vapor is condensed by passing it through a second set of heat exchangers containing cold water pumped from depths of up to 1,000 meters. In the open cycle concept, a partial vacuum is used to evaporate warm surface water. The vapor expands and is used either to drive a low pressure turbine (Claude Cycle) or to lift the vapor to a height where the recondensed liquid can fall through a hydraulic turbine (lift cycle). Again, cold water drawn from depth is used to recondense the vapor. A potentially valuable by-product of the ocean cycle concept is this fresh water condensate.[2] Major subsystems common to all OTEC plants are the warm and cold water intake and discharge systems, platform system and power transfer system. Three major configurations have been proposed for OTEC plants: the land based, shelf-mounted and floating configurations.

## 3. UNITED STATES PROGRAM: DEVELOPMENT STATUS

In the U.S. program, the research and development effort sponsored by the U.S. Department of Energy (DOE) is directed at the evaluation, development and testing of major high risk OTEC subsystems.[2] DOE has also conducted extensive environmental studies to determine both the effects of the environment on OTEC and of OTEC on the environment.[3] Finally, DOE has sponsored a number of design studies for fully integrated OTEC systems ranging in size from 1 to 40 MWe.[4] These activities have culminated in the initiation of design studies which could lead to the commercial construction, deployment and operation of a fully integrated 40 MWe OTEC plant as early as 1987. The preliminary design phase of the proof of concept experiment is a cost-shared venture between DOE and a consortium headed by the Ocean Thermal Corporation. A summary of the design proposed for the experiment is shown in Table 1.

**Table 1 Proof of Concept Experiment, Preliminary Design**

| | |
|---|---|
| Contractor: | Ocean Thermal Corporation |
| Site: | 180 m offshore Kahe Point, Oahu, Hawaii; 9 m depth |
| Platform: | Reinforced concrete plant on prepared foundation |
| Power System: | 40 MWe net capacity (warm water supply enhanced by effluent from existing fossil fuel power plants) |
| Heat Exchangers: | Horizontal shell and tube titanium construction |
| Working Fluid: | Ammonia |
| Cold Water Pipe: | 10 m diameter, 5700 m long lightweight concrete |
| Power Cable: | Overhead to shore |

Source: Reference 4

The proof of concept experiment will fill a major void in the OTEC development program. Although there have been significant accomplishments at the subsystem level[5], there is no existing experience with the operation of fully integrated prototypes (> 1 MWe systems). As such, issues relating to the construction, deployment, operation, survivability, maintainability, and overall cost competitiveness of OTEC remain to be resolved. This is especially critical since OTEC requires a high initial capital investment which is offset by zero fuel costs over an extended plant life (on the order of 30 years).

The U.S. program has included the deployment of a small demonstration system that proved OTEC can produce net energy. In 1979, a private industrial consortium, lead by Lockheed Missiles and Space Company, deployed a 50 KWe gross (10-15 KWe net) power, closed cycle, floating OTEC plant called "Mini-OTEC" off the Kona Coast, Hawaii.[6] Further experience with the deployment and operation of 1 MWe OTEC components was obtained during the DOE sponsored OTEC-1 heat exchanger test program conducted in 1980.[2] These systems have clearly demonstrated that OTEC is a potential source of power generation.

The U.S. research and development program in OTEC continues to focus on the reduction of risk associated with critical components. A pilot plant (40 MWe) one-third scale at-sea test of both suspended and bottom mounted cold water pipes is in progress in Hawaii[7,8]. In addition, the installation of the OTEC-1 four foot diameter cold water pipe to serve the Seacoast Test Facility will be completed in 1983. DOE is cost sharing the expansion of the Hawaii Natural Energy Laboratory with the State of Hawaii. This will accommodate larger scale (up to 1 MWe) open and closed cycle experiments at the Seacoast Test Facility as well as provide intake water to solar pond and mariculture experiments.

 

## 4. UNITED STATES PROGRAM: DEVELOPMENT POTENTIAL

In a recent assessment prepared for the 1981 United Nations Conference on New and Renewable Sources of Energy, OTEC was assessed as shown in Table 2:

Table 2 OTEC Assessment

| | |
|---|---|
| Technology: | Ready as verified by experience with Mini-OTEC, OTEC-1, and CWP At-Sea test programs |
| Resource: | Good availability in US islands, fair only in US Gulf Coast |
| Fossil Fuel Displacement: | High for US islands<br>Poor for US mainland |
| Acceptability: | Good, environmentally benign, enhanced fishing |
| Financing: | Poor |

Source: Reference 9

In their recent report to Congress[10], the National Oceanic and Atmospheric Administration indicates that for OTEC a permitting and licensing framework is in place and guidelines are available. At least three consortia have active preapplication consultation status:

- Ocean Thermal Corporation for a 40 MWe shelf-mounted system off Oahu, Hawaii
- Inter Energy for land-based modules leading to a 50 MWe system on Cabras Island, Guam
- OTEC International for a 10-15 MWe open cycle (for fresh water production and electricity) land-based system on St. Croix, USVI

OTEC's future appears to be critically tied to the success of the proof of concept experiment (pilot plant) program. Without the validation of production cost estimates and operational performance goals which that system can provide, investors will continue to consider OTEC high risk and will not provide the required capital intensive financing.[11]

From the perspective of baseload additions, it has been estimated that some 1600 MWe of added capacity will be required in the US islands by 1995. In 1990, OTECs in the 5-50 MWe size range could be life-cycle cost competitive with coal (both technologies at 25-35 ¢/kWh) and much cheaper than oil (at 50 ¢/kWh) for these markets.[11,20]

## 5. INTERNATIONAL PROGRAMS: DEVELOPMENT STATUS

OTEC systems in various states of development and sponsored by several different countries are summarized in Table 3. All are prototypes at 10 MWe or less. The need for producing fresh water as well as electricity is expressed in the selection of open cycle in several concepts. Most systems are either land-based or very near shore shelf-based reflecting a choice to minimize risk in this early development stage (no suspended cold water pipes or electrical power riser cables and no moorings). Critical OTEC components are typically being developed by the project sponsoring consortium team member in their laboratories.

## 6. INTERNATIONAL PROGRAMS: DEVELOPMENT POTENTIAL

The OTEC thermal resource area encompasses a large number of developing island countries who have common factors to address in selecting energy options. Most have an increasing demand for electricity and fresh water (expanding industrial and agricultural demands). Nearly all are fully dependent on imported oil and suffer from high transportation costs and unreliable sources. Existing equipment in oil fired plants tends to be aging and difficult to maintain. Present cost of electrical generation often is several times that for countries with indigenous energy resources. Examples include American Somoa at 15-25 ¢/kWh and Tahiti at 10-40 ¢/kWh.[1]

Additional factors that require consideration for developing tropical island countries include: typically weak currencies, limited history of self-government, weak technological and organizational skills, remote locations, and being subject to strong tropical storms and salt air

Table 3 International OTEC Programs

| PROGRAM | REF | YEAR OF OPERATIONS | LOCATION | SIZE (MWe) | TYPE | CYCLE | PRODUCTS | SPONSORS |
|---|---|---|---|---|---|---|---|---|
| French | 12, 13 | 1988 | Tahiti | 5 | Lagoonbased | Open | Electricity<br>Freshwater | French Government<br>CNEXO, CGE-Alsthom<br>Empain Schneider |
| India | 14 | n/a | Tamil Nadu | 1 | Floating | Closed | Electricity | Indian Government<br>Indian Inst. Tech.<br>Bharat Heavy Indus. |
| | | 1987 | Lacadive Isl<br>(Arabian Sea) | 1 | Landbased | Closed | Electricity | same |
| Japan | 15 | 1981 | Nauru | 0.1 | Landbased | Closed | Electricity | TEPSCO, MITI |
| | | n/a | Nauru | 10 | Landbased | Closed | Electricity | TEPSCO |
| | | 1982 | Tokunoshima | 0.05 | Landbased | Closed | Electricity | Kyushu Elec Co. |
| | | n/a | Okinawa | 1<br>3 | Floating<br>Shelfbased | Closed<br>Closed | Electricity<br>Electricity | n/a<br>n/a |
| Netherlands | 16, 17 | 1985 | Bali | 0.5 | Landbased | Closed | Electricity | Delta Marine/HBG |
| | | n/a | Curacao | 10 | Landbased | Open | Electricity<br>Freshwater<br>Aquaculture | same |
| Sweden | 18, 19 | n/a | Jamaica | 1 | Landbased | Open | Electricity<br>Freshwater | Petr. Corp. Jamaica<br>Alfa-Laval, SWECO<br>Oy Wiik |

corrosion. There is also a common desire in these island nations not to centralize their populations, but to put new energy sources where the people are located.[21]

Given these factors, there is strong enough interest in OTEC to pursue the projects identified in the previous section (Table 3). In addition, planning activities are underway for OTEC development in Saipan, Tinian, and Tutuila in the Pacific[21], both Haiti and Barbados[23] in the Caribbean and Taiwan[22]. There is also some Soviet interest in an arctic OTEC.[24]

## 7. CONCLUSIONS

The prospects for near term development of OTEC look quite promising. The single most important barrier appears to be the uncertainty of capital intensive financial backing associated with unproven cost estimates and the absence of operating performance validation. Given the pace of development of the United States proof of concept (pilot plant) program and several international prototype development projects, one can speculate that these uncertainties will be soon removed. If, simultaneously, fossil fuel prices escalate as in the recent past, near term OTEC development would seem a certainty.

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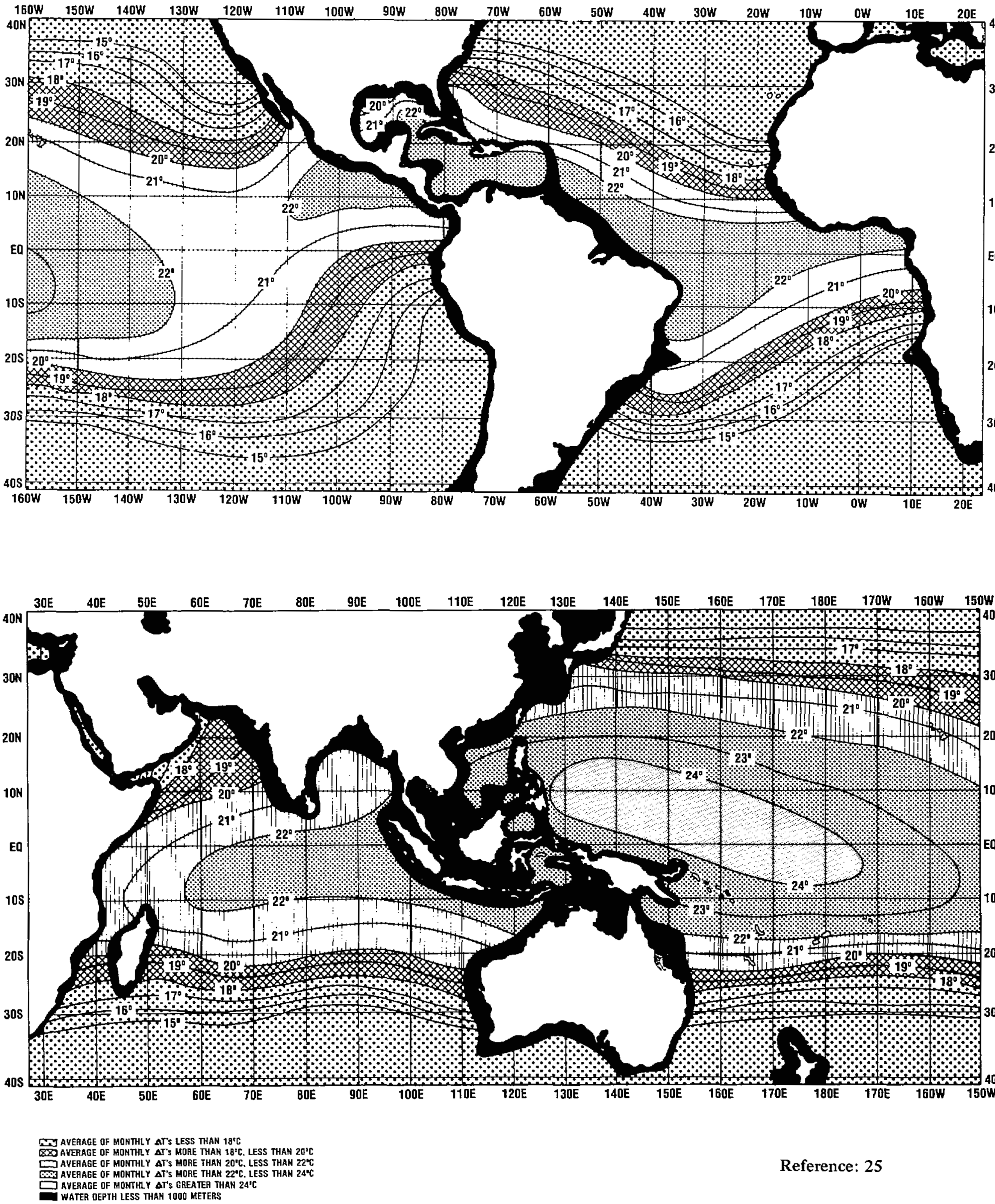


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Figure 1. ΔT(°C) Between Surface and 1000 Meter Depth