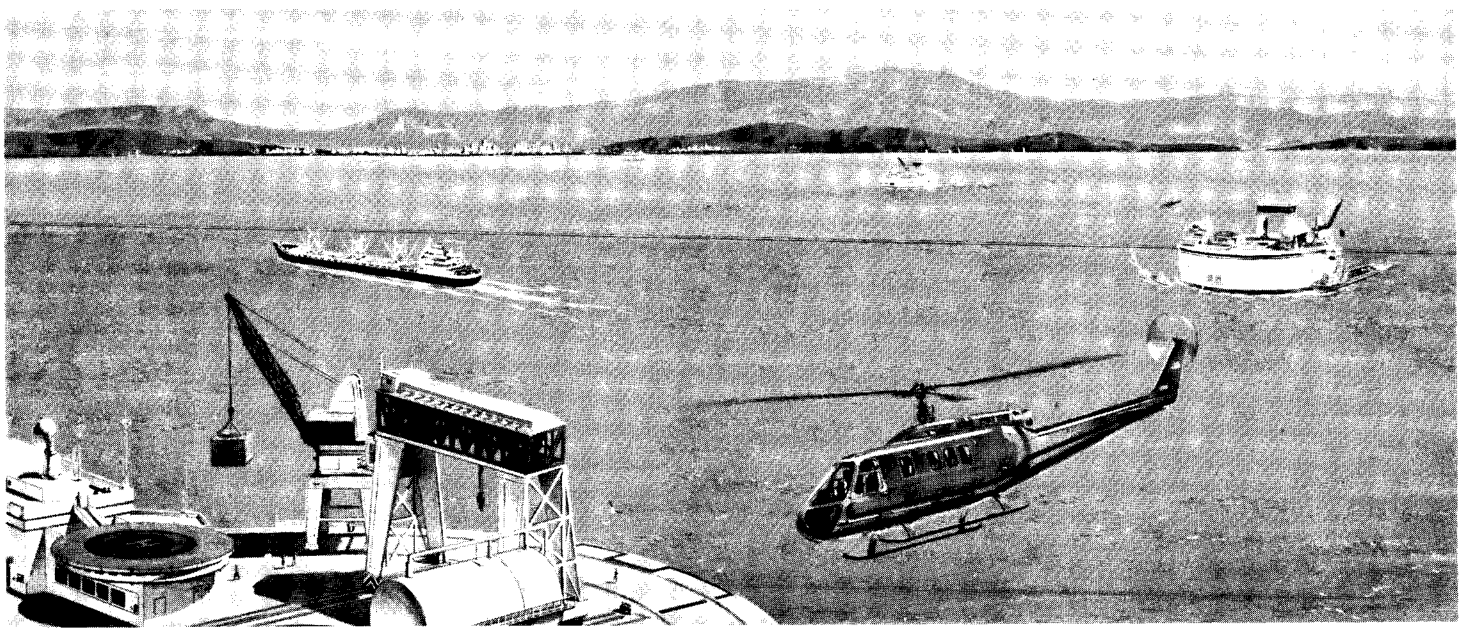
SERI

The Ocean Option

SERI/SP-732-334

The Ocean Option
Abundant Energy from the Seas



The oceans have served us well for thousands of years, providing among other things sea lanes for the shipping of goods. More and more, such shipping involves oil and natural gas, the fossil fuels so vital to modern life yet such an increasing threat to both our economy and the environment. Fortunately, the oceans that oil tankers sail on may be one solution to our growing energy problems:

Energy from the oceans can begin to provide electric power for U.S. islands in the 1980s, and for the U.S. Gulf Coast in the 1990s. The Department of Energy's "ocean energy option" foresees the development of safe, clean, competitively priced power from a virtually unlimited source.

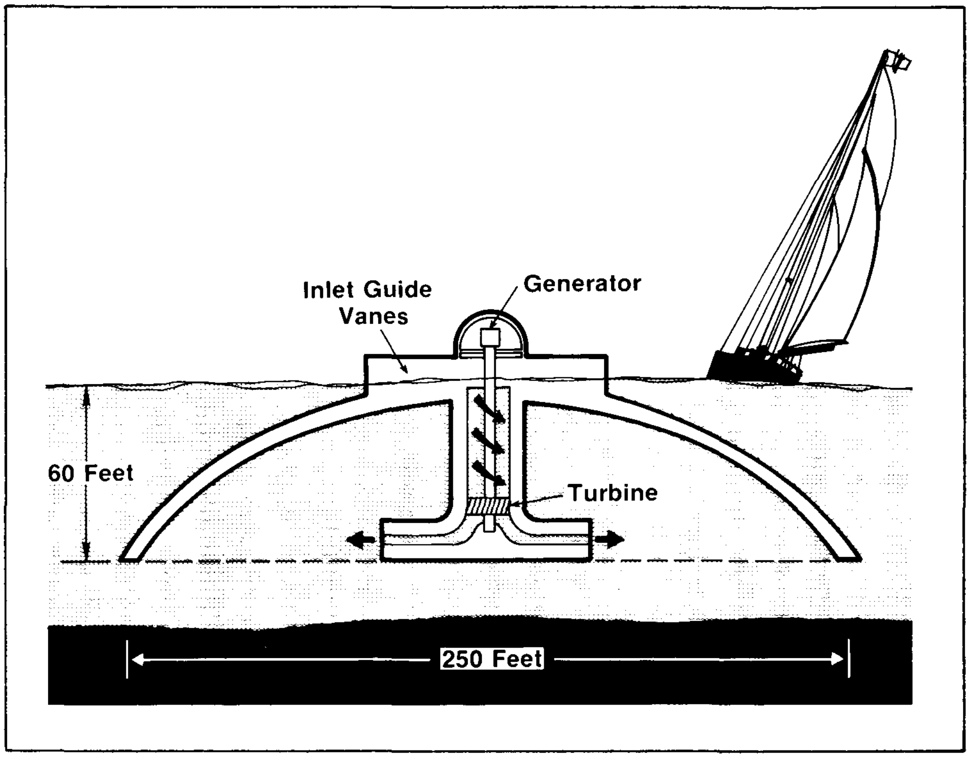
The Ocean Thermal Concept

Almost three-fourths of the solar energy striking Earth falls on the oceans, creating a vast reservoir from which we can extract power. DOE's Ocean Systems Division is investigating several approaches to ocean energy, including waves and currents. Wave energy is an indirect form of solar energy: wind creates waves, and wind itself is caused by the sun's heat. Ocean current energy conversion would tap sources like the Gulf Stream along the Eastern seaboard with huge windmill-like turbines to produce electric power. Facilities with outputs of about 100 megawatts are being considered.

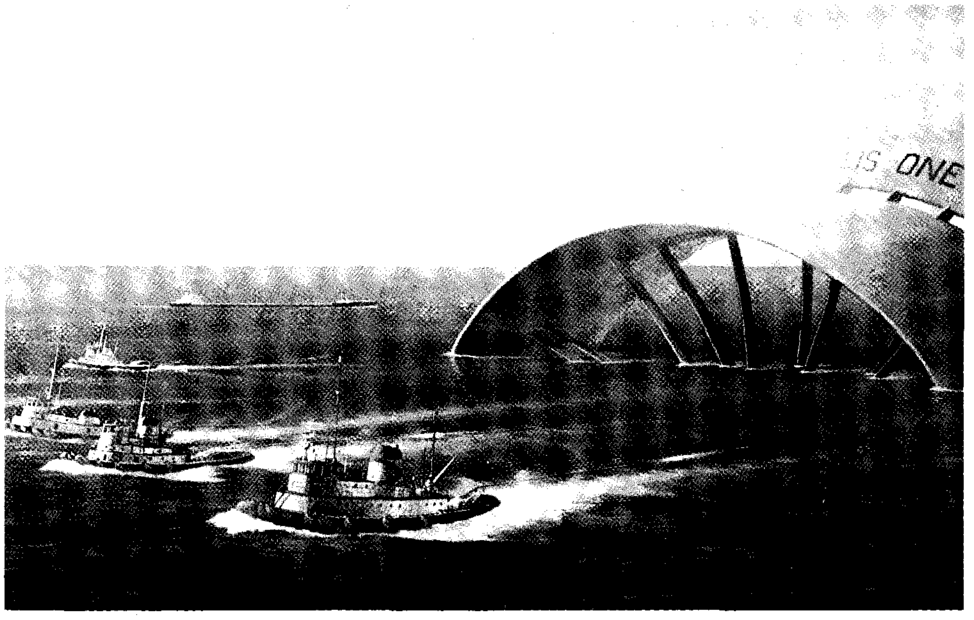
The major ocean energy option, however, is Ocean Thermal Energy Conversion, OTEC for short. The OTEC concept is simple:

The sun heats the surface of tropical and subtropical waters to temperatures higher than those in deep water. In many areas this temperature difference is enough to run an engine, and the usable heat energy of all the oceans has been estimated at about 1 billion megawatts on a continuous basis.

Converted to electricity at an efficiency of only 3 percent, this resource would yield about 30 million megawatts of electric power. For comparison, the United States will require about 1 million megawatts of electricity by the year 2000.

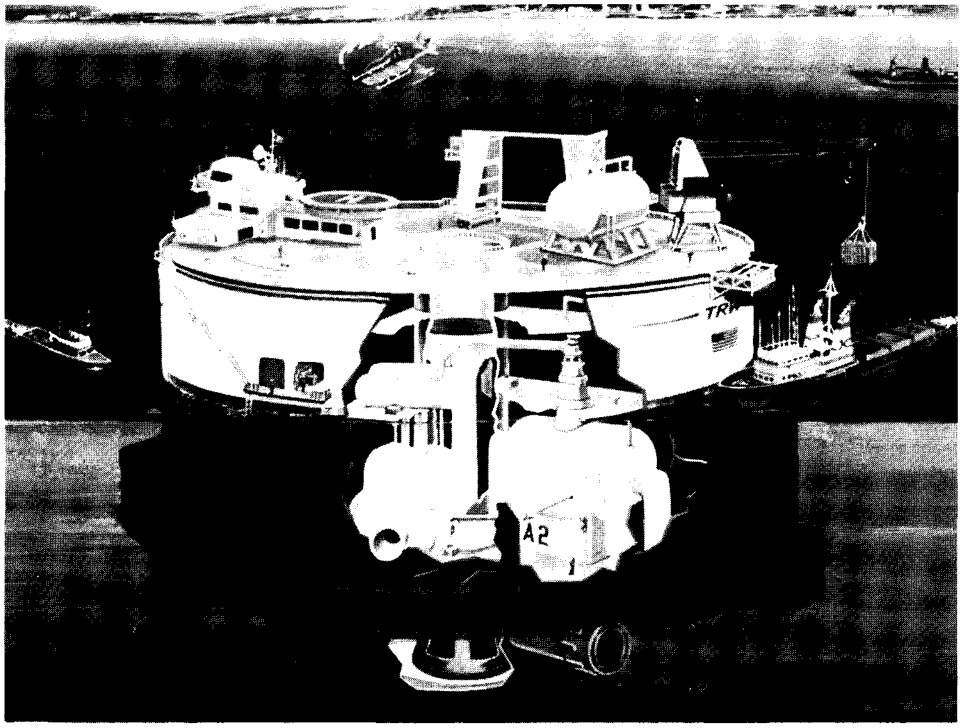


Lockheed's DAM-ATOLL wave turbine



The Coriolis ocean current turbine by Aerovironment, Inc.

The ocean thermal concept was first suggested in 1880 by Frenchman Arsene d'Arsonval. His idea was to use the temperature difference between the Seine River and a mountain glacier to run a heat engine. Many years later, d'Arsonval's student, Georges Claude, extended the idea to using sea water off the coast of Cuba to provide the needed temperature difference. Claude succeeded in producing 22 kilowatts of power during a test in 1929 but Claude's prototype plant was only a qualified success, since its equipment used more power than the plant produced. The easy availability of cheap fuels left OTEC technology undeveloped for decades. During the fuel crisis of 1973, however, OTEC became a serious candidate as an energy alternative.

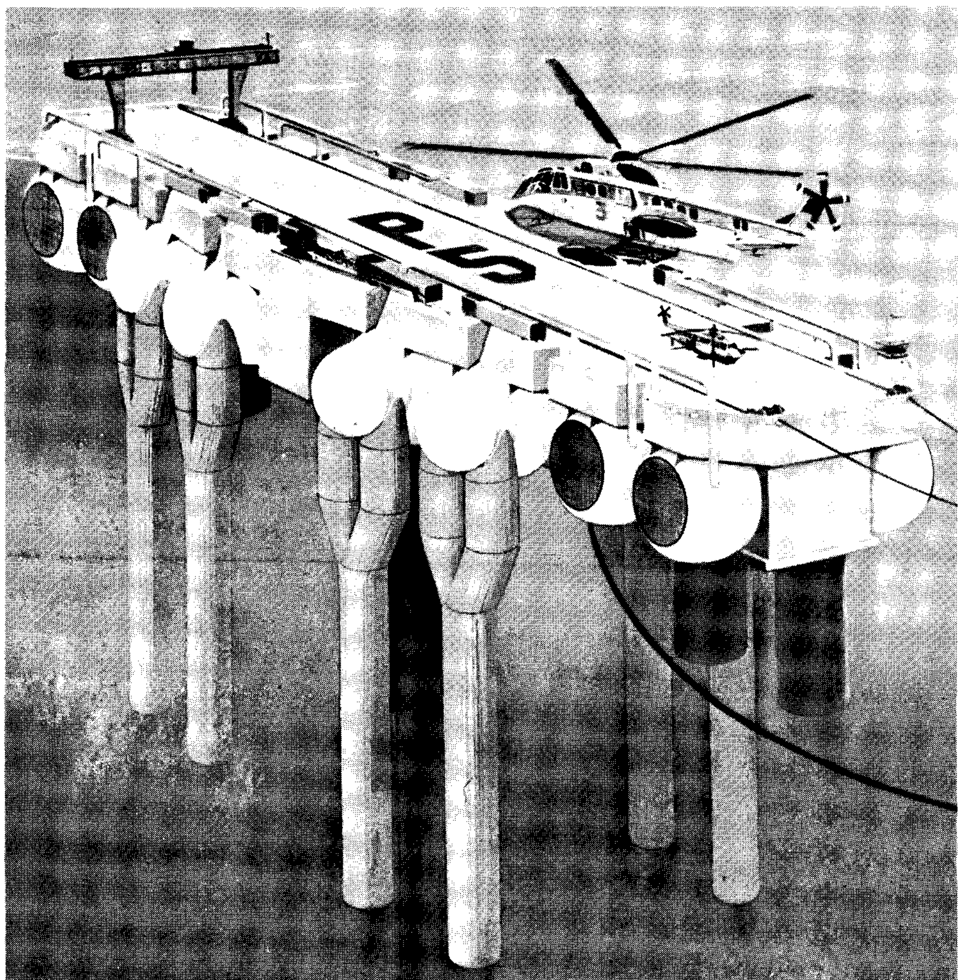


An OTEC platform design by TRW, Inc.

OTEC Timetable

The ocean energy resource is an exciting technical challenge. DOE's Ocean Energy Systems Program emphasizes the demonstration of commercial offshore OTEC power plants converting ocean thermal gradients into electric power in the near future.

Under DOE guidance, some 200 contractors, including such firms as Westinghouse, TRW, Lockheed, Global Marine, and General Electric are designing and testing heat exchangers, power systems, and submarine cables as well as assessing the environmental and economic consequences of large-scale ocean thermal power plants.



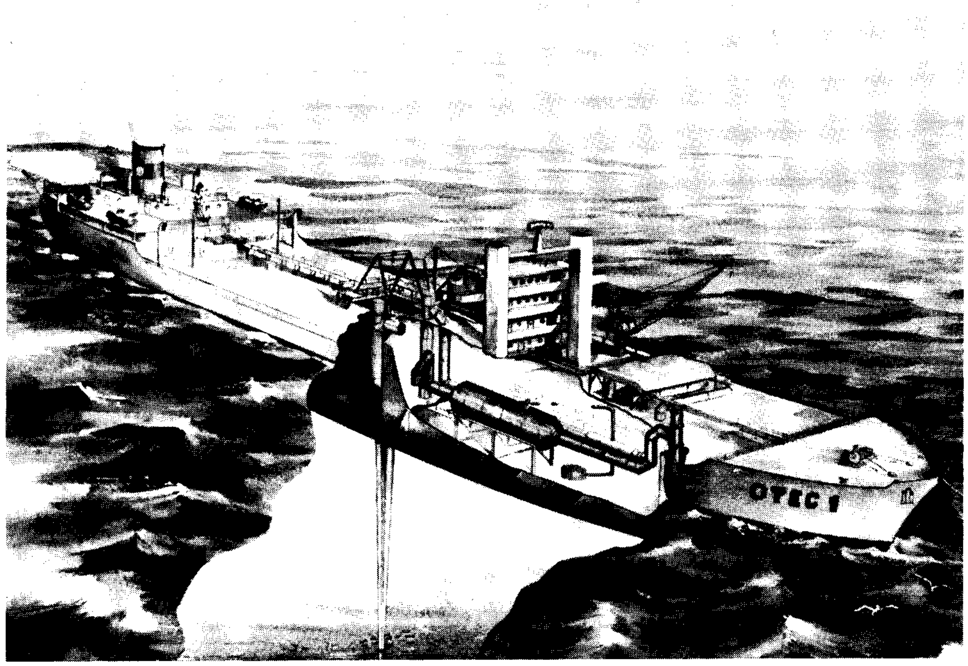
Lockheed developed this OTEC plantship design

A working platform, called mini-OTEC, was launched in May 1979 off the coast of Hawaii in a joint effort funded by Hawaii, Lockheed, the Dillingham Corp., and Alfa Laval. This facility was used to evaluate such problems as biofouling and corrosion.

Current activities include the deployment of OTEC-1, a 1-megawatt engineering test facility built into an existing navy tanker. Candidate heat-exchangers will be tested under ocean conditions when OTEC-1 operates in mid-1980.

By 1981, a conceptual design competition will lead to several candidate concepts of a pilot plant with a 40 megawatt capacity. DOE plans to begin operation of this pilot plant by 1985. In the 1990s, the goal is to implement DOE's island commercialization strategy of displacing conventionally produced electricity with OTEC-produced power in U.S. islands.

Mini-OTEC producing electricity off the coast of Hawaii

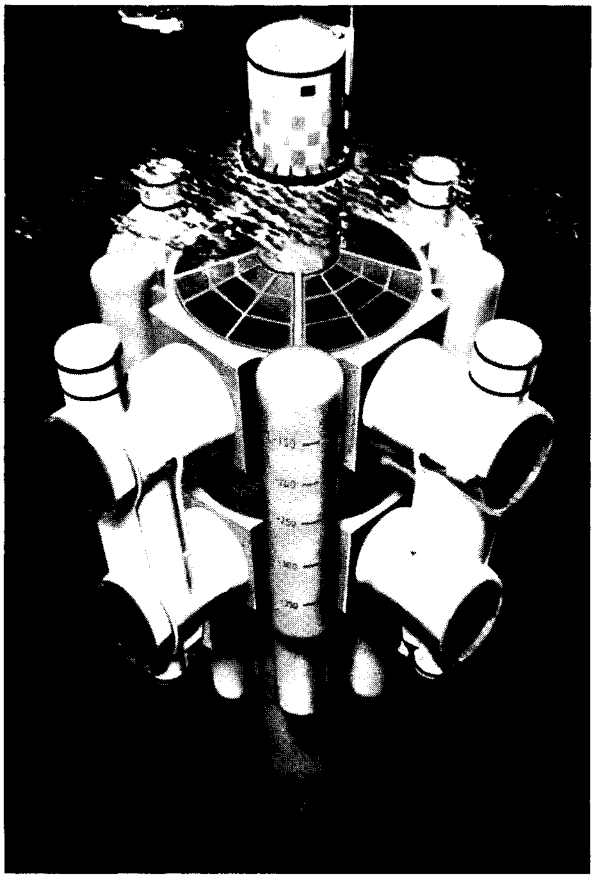


DOE's OTEC-1 tests components rated at up to 1 megawatt

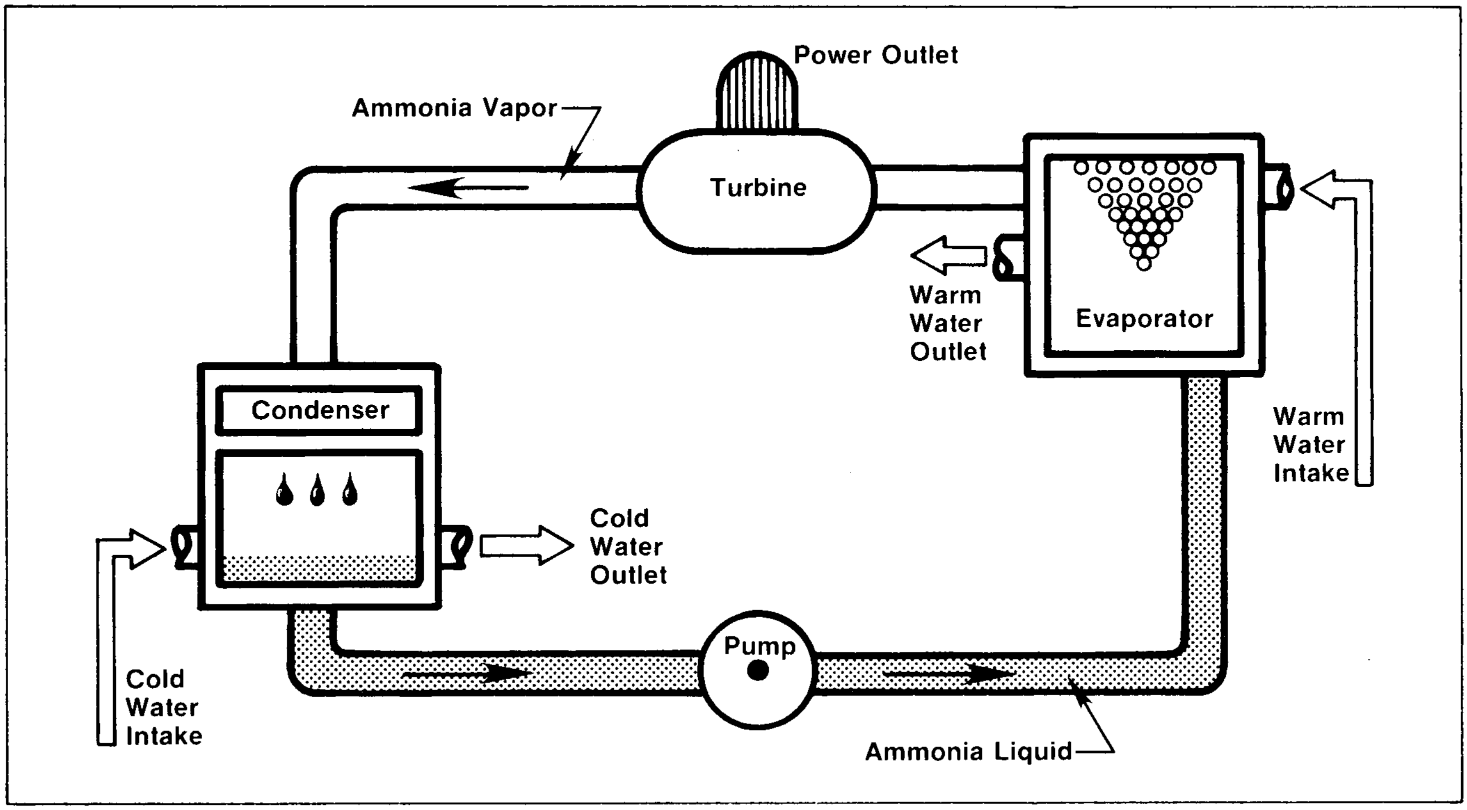
Design Considerations

A number of alternate OTEC approaches are being investigated. One is the "open-cycle" design in which warm sea water is evaporated into steam to drive a large turbine. The steam is then condensed by cold ocean water and the cycle begins again. Condensed water can be used as a source of fresh water or put back into the ocean. This was the design used in Claude's OTEC plant operated in Cuba.

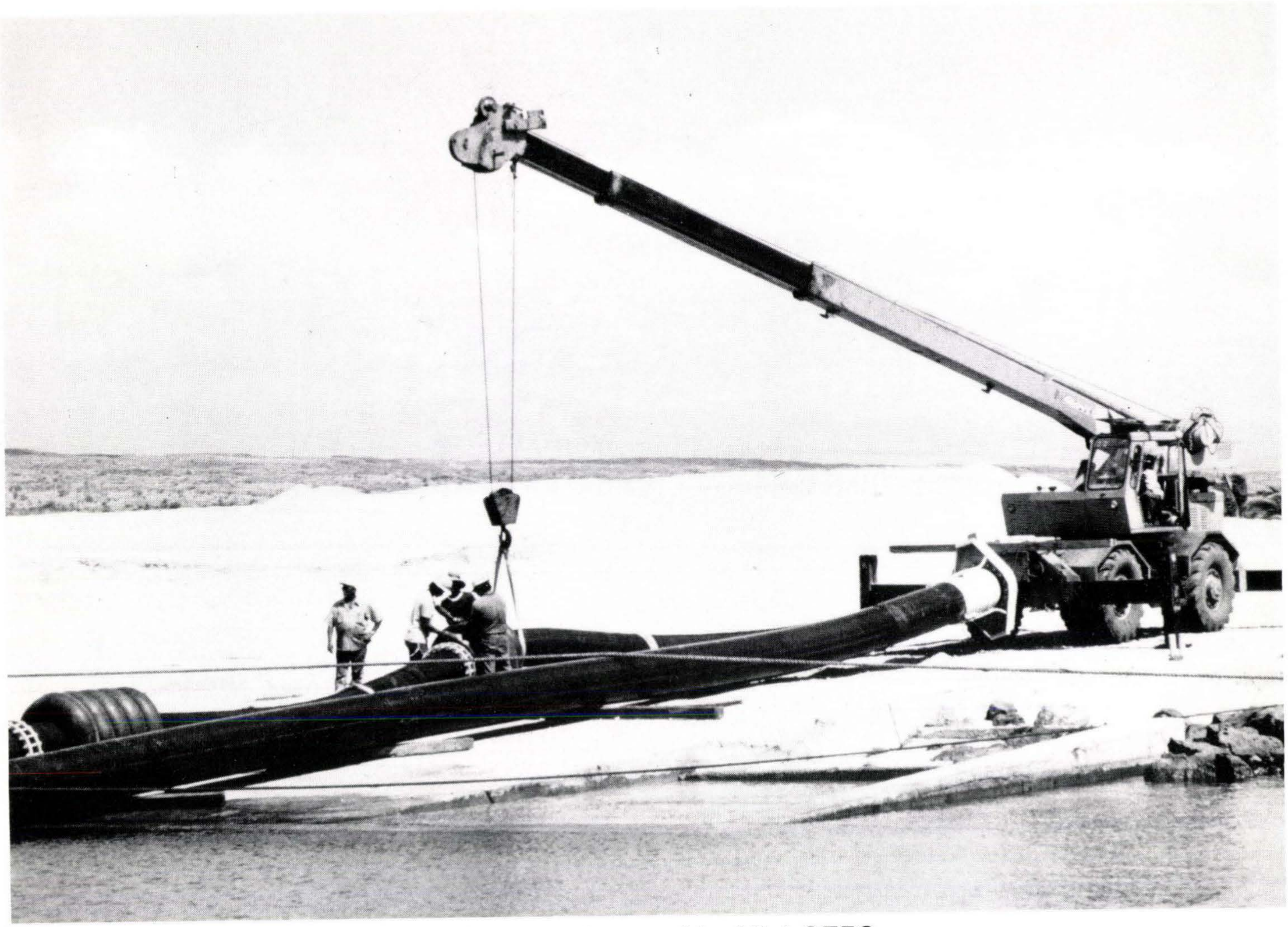
Research also is under way on innovative "lift-cycle" designs that raise water as a foam or mist, condense it, and let it fall to operate a hydraulic turbine as in conventional hydro-



An OTEC platform design by Lockheed



A typical closed-cycle OTEC system



Workmen assemble the 2000-foot cold water pipe used by Mini-OTEC

electric power plants. The Solar Energy Research Institute (SERI) is managing the development of these open-cycle and innovative designs.

The DOE near-term development program focuses on "closed-cycle" designs in which sea water heats a working fluid such as ammonia, which in turn drives a much smaller turbine than is required in open cycle system. The ammonia vapor is then condensed by cold sea water to keep the cycle going.

OTEC plants operate at lower efficiencies than conventional power plants because of the relatively small temperature difference involved. However, a low efficiency is tolerable since there are no fuel costs and the system is expected to be economic.

As with any new concept, there are problems to be solved. OTEC power plant components are subject to corrosion in sea water, and heat exchangers and other components may be fouled by marine organisms. OTEC plants offer minimal environmental effects. However, DOE is funding environmental studies so that we are certain there are no harmful local effects, or long-term changes because of heat removal from the ocean.

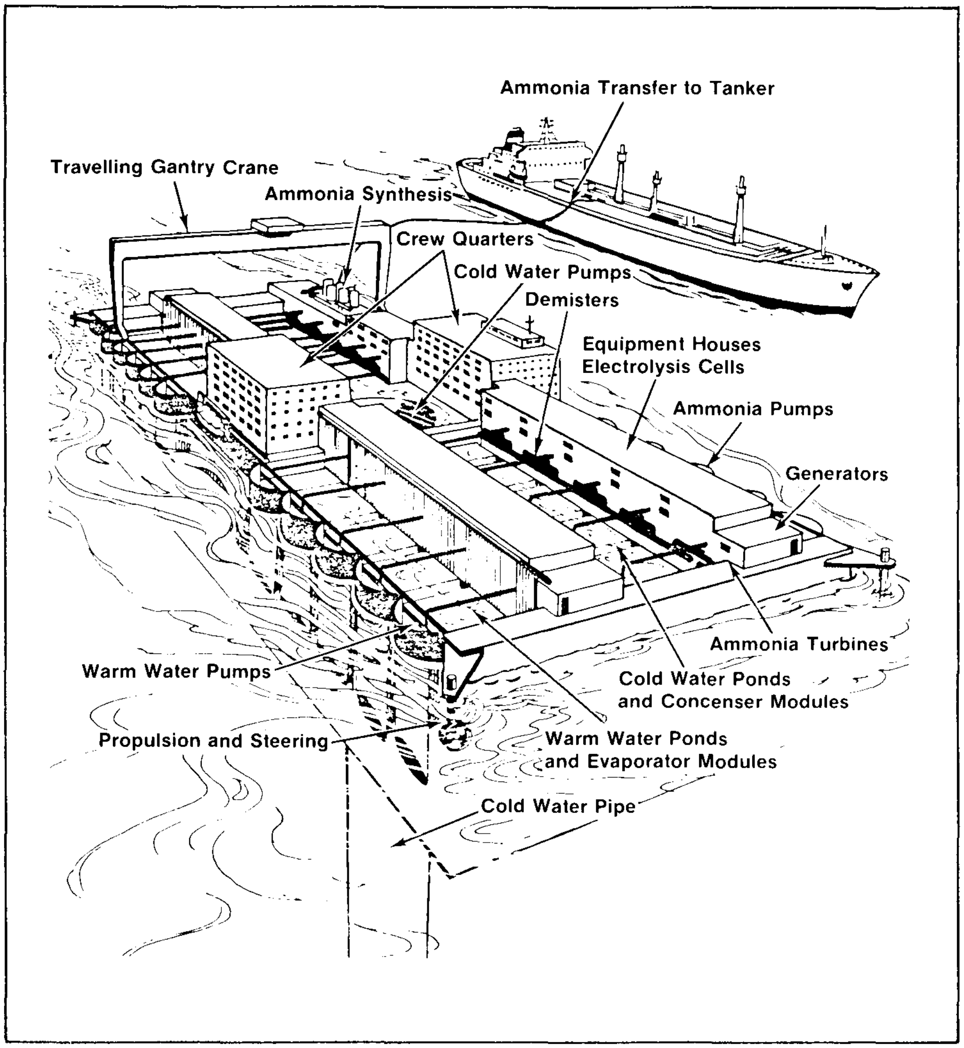
The very large size of OTEC plants presents challenges in construction and assembly, as well as anchoring in heavy seas. Transmission of electric power by submarine cable over long distances will require new direct-current technologies. However, careful studies indicate that OTEC plants are technically feasible and will have negligible effects on the environment.

Advantages of OTEC

The oceans are huge reservoirs of thermal energy stored for use at any time, so OTEC plants can produce electricity 24 hours a day the year-round. This makes it a "baseload" or continuous source of power that can be transmitted to shore and fed into a utility power grid. Furthermore, OTEC is a clean source of power and can be located out of sight of land on inexpensive "real estate."

DOE has examined the market potential for OTEC products other than electricity. These include aluminum, ammonia, hydrogen, chlorine, and other chemicals. OTEC production costs of chemical-energy carriers such as methanol, or thermal-energy carriers such as molten salts, and of refining lithium for use in batteries also have been studied. Another possibility is that manufacturing plants using OTEC power can be sited near raw materials. Aluminum plants are an example: bauxite ore can be delivered short distances to an OTEC plant by cheap water transport.

Ammonia synthesized aboard floating OTEC plants (using nitrogen removed from the air and hydrogen electrolyzed from sea water) may become an attractive alternative for the large fertilizer market which now uses ammonia made from natural gas. Floating OTEC plants have economic advantages over anchored plants including the elimination of cable and reduction of station-keeping costs.



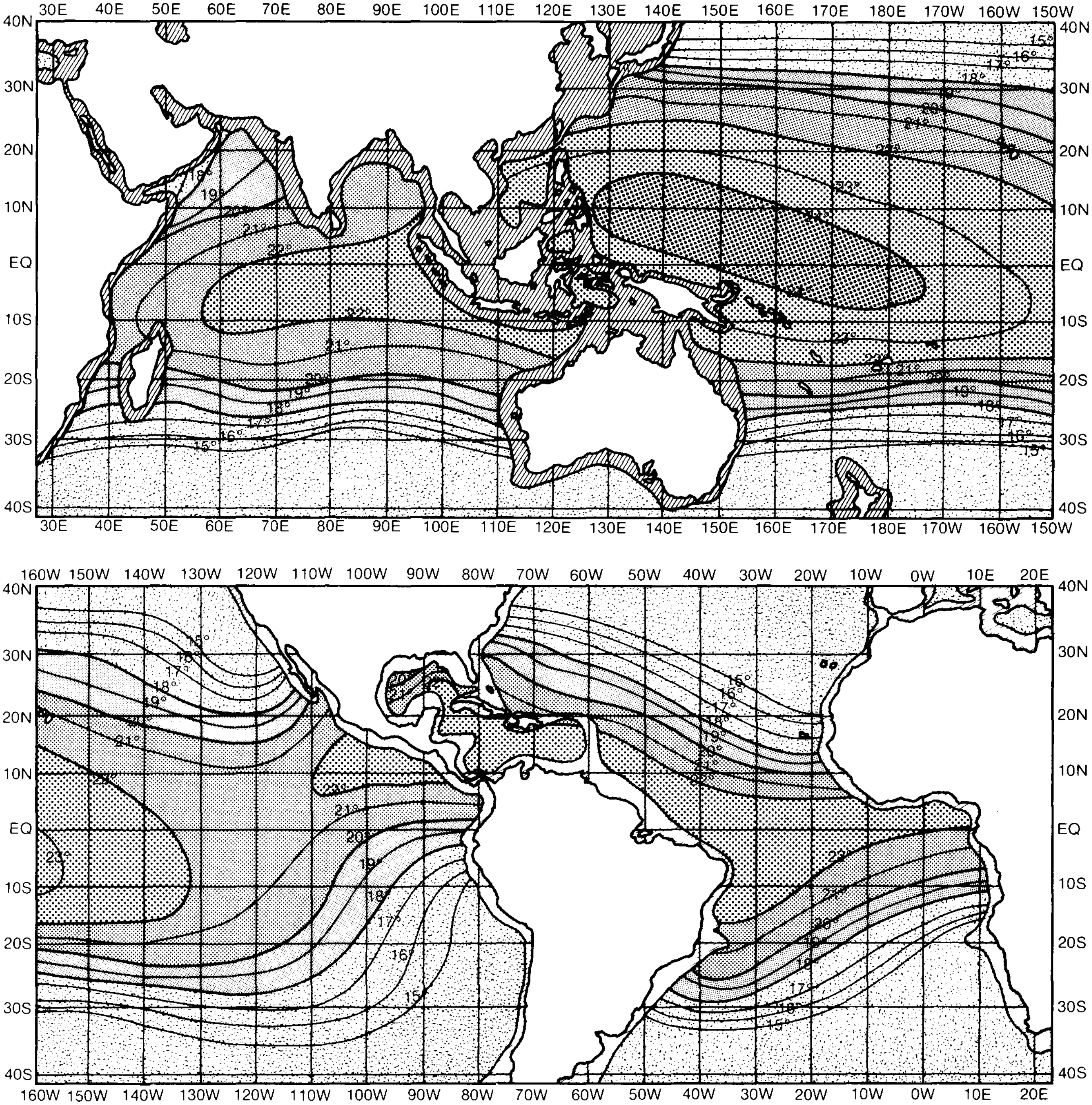
An ammonia plantship designed by the Applied Physics Laboratory at Johns Hopkins University

Another kind of by-product may make OTEC even more attractive. Fresh water is as scarce as energy in some areas, and a 100-megawatt open cycle OTEC plant could produce millions of gallons of fresh water daily by desalting warm sea water in the plant's boilers. OTEC plants may also create more productive fisheries in the waters surrounding them, since pumping cold water from the depths also brings up nutrients that may attract fish to the area. The Humboldt Current, a natural cold-water upwelling off the coast of Peru, produces a fishery supplying about 20 percent of the commercial fish in the world.

Large Scale Distribution of

OTEC Thermal Resource

ΔT(° C) Between Surface and 1000 Meter Depth



From a global standpoint, OTEC offers a substantial potential. This huge ocean resource can provide large amounts of electric power to many nations in tropical and subtropical regions up to about 25 degrees of latitude on either side of the equator. Closer to home, sizable ocean thermal resources are available to the United States.

The amount of OTEC power that can be supplied by cable to Gulf Coast locations such as New Orleans and Tampa is estimated tens of gigawatts (billion watts) of electricity. This resource could contribute substantially to the electrical power demands projected for the southern United States in the year 2000 and beyond.

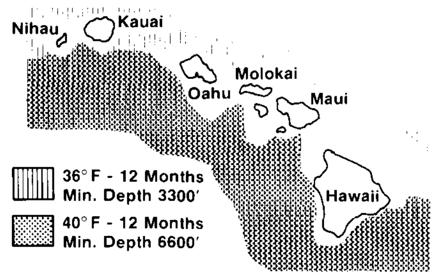
The "Island Strategy"

In addition to prime OTEC areas in the Gulf of Mexico, there also are excellent resources a few kilometers off major U.S. islands including Hawaii, Puerto Rico, the Virgin Islands, Guam, American Samoa, and Micronesia. The ocean thermal resource near U.S. islands far exceeds the power required to replace existing electrical production and to satisfy expected increases during the next century. Puerto Rico and Hawaii in particular offer excellent early markets for OTEC because their electric power is now produced largely from imported oil. OTEC plants can also be matched to typical island electric power requirements, starting with modules as small as 10 megawatts. And because the plants can be sited very close to islands, short lengths of conventional alternating-current cable can transmit electrical power to shore.

Much of the oil now used to produce electricity could be displaced by OTEC power production at U.S. islands, especially as existing gas turbines are amortized and phased out. Each megawatt of oil-derived electricity is equivalent to about 40 barrels per day of oil displacement. The eventual production of 2000 megawatts of OTEC electricity for Puerto Rico alone would save more than 80,000 barrels of oil a day. Achievement of this island strategy in the 1990s would help lead to larger OTEC plants serving the Gulf Coast market.

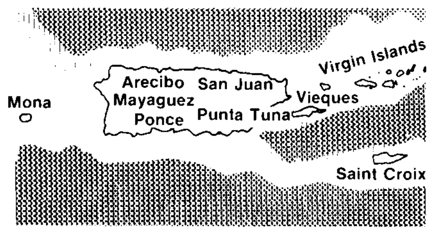
Thermal Resources

Hawaiian Islands



Note: Seasonally Averaged Temperatures Used In Analysis

Puerto Rico

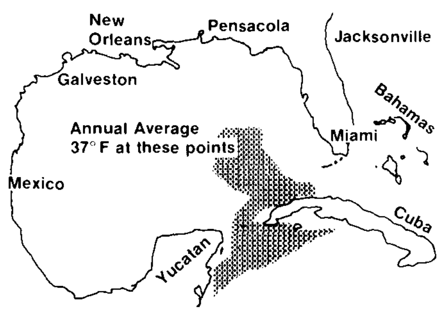


38° F - 12 Months, Min. Dept 3000′

40° F - 12 Months, Min. Depth 6000′

Note: Monthly - 1° Square Data Used in Analysis

Gulf of Mexico



36° F - 9 Months

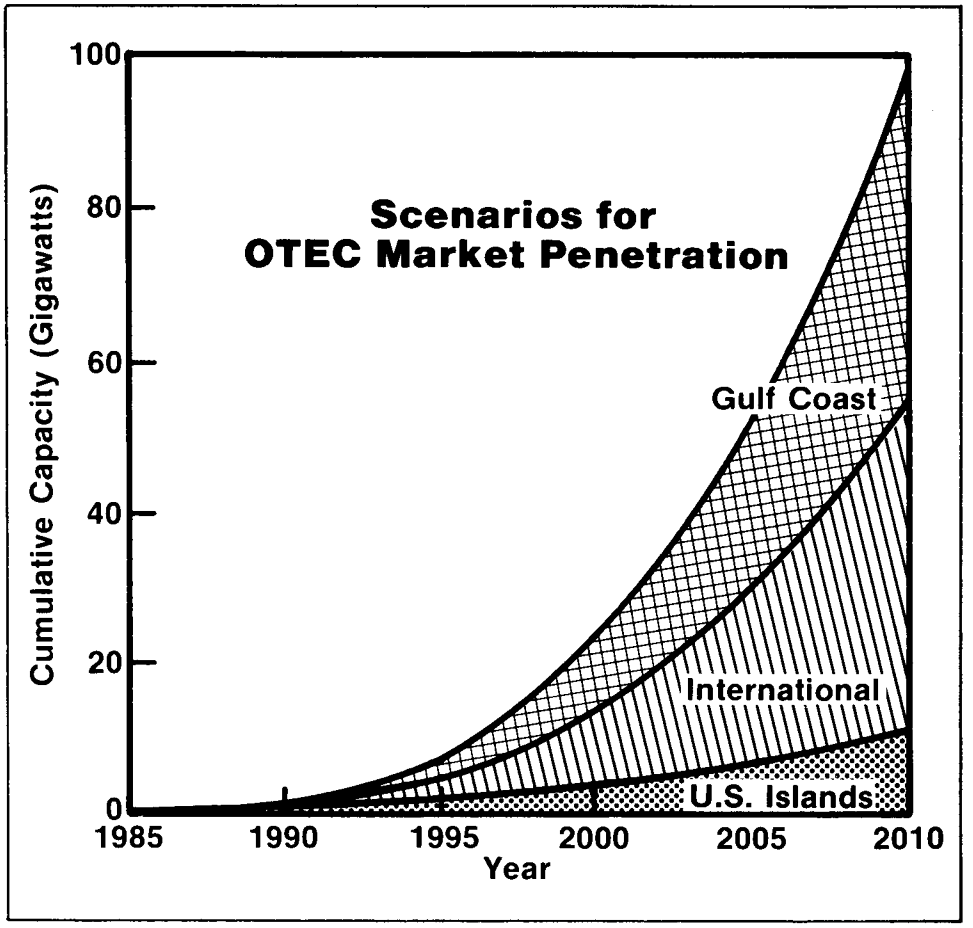
36° F - 12 Months
Depth to Resource 3960′

Note: Monthly 1° Square Date Used in Analysis

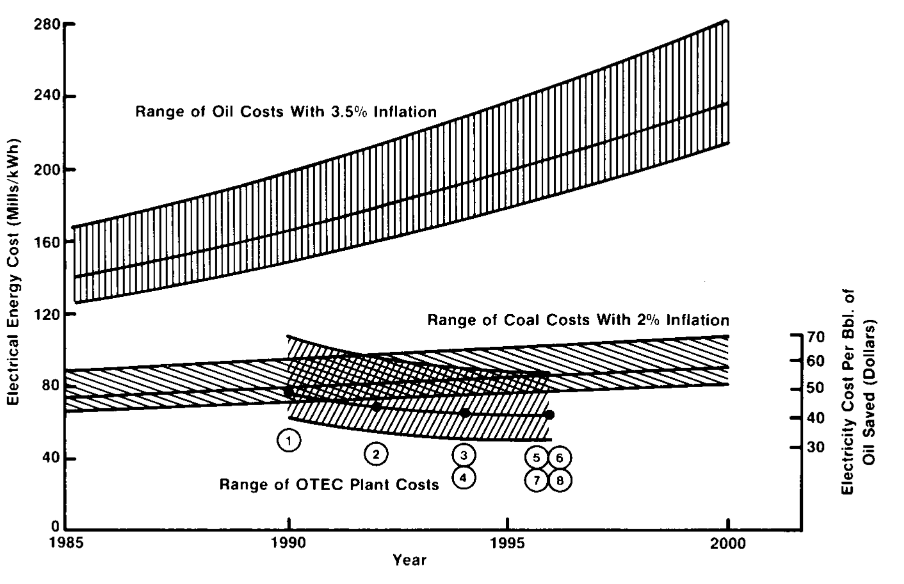
OTEC In Our Future

OTEC offers the prospect of abundant supplies of clean ocean energy and the wealth of useful byproducts is exciting. Georges Claude, after operating the world's first OTEC plant at Matanzas Bay in Cuba, received an award from the American Society of Mechanical Engineers in 1930. On that occasion, Claude said: **"I affirm my faith in the realization of wonderful plants running ceaselessly throughout the year, unaffected by the seasonal scarcity of water in streams or variations in the cost of coal; and I hold all this is not the task of a remote future, but one of tomorrow."**

Fifty years later, DOE's Ocean Energy Systems Program has set its sights on that tomorrow. And Gov. Carlos Romero-Barcelo of Puerto Rico, addressing the 6th OTEC Conference in June 1979, said: **"There is no question that one of the last great sources of untapped raw energy on earth is the oceans. Their tides, currents, waves, salinity gradients, and temperature differences offer enormous energy potential."**



Cost Projection for the First Eight 250 Megawatt OTEC Plants at Puerto Rico (1980$) (Public Financing)



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