Chapter 1

Introduction

Introduction

An Idea to Fill a Need

In 1926, Georges Claude announced to the French Academy of Science his intention to develop equipment which would produce “torrents of power” from the difference in temperature between the top and the bottom of the oceans. [1]

Claude, the industrial and physical chemist whose work with gases in tubes led to the development of the neon sign, called for immediate action on his ocean energy plan because “the Federal Oil Conservation Board of the United States estimates that the United States has only enough oil to last for 6 years.”[2]

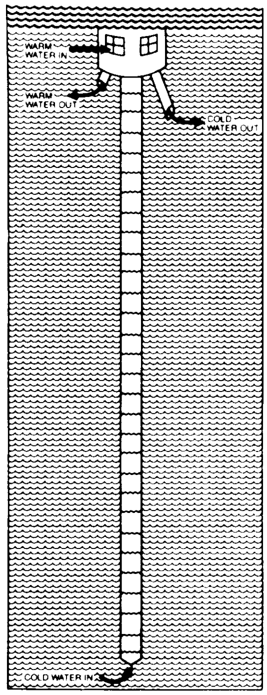
These dire 1926 predictions ascribed to the Federal Oil Conservation Board did not come true on schedule. But the oil crisis of that period heightened Claude’s interest in extracting energy from the oceans. Now, 50 years later, the United States is faced with an energy crisis, and the dwindling supplies and high prices of fuel have rekindled interest in the oceans.

The Source of Ocean Thermal Energy

The source of ocean thermal energy is the Sun. The oceans act as huge natural collectors, catching and storing solar energy as heat in the surface waters. This stored energy can be extracted by using the heat from the surface waters to evaporate a fluid; passing the resulting vapor through a turbine; and then returning the vapor to liquid state by chilling it with cold water from the deep ocean. The turbine, in turn, can be used to power equipment or to generate electricity. The process is similar to that used in steam powerplants.

‘Daniel Behrman, *The New World of the Oceans,* (Boston: Little Brown and Co., 1969), p. 60.

[2]Ibid.



A G@mrk OTEC Plant

The idea of converting the stored ocean energy to useful power originated with French physicist Jacques d’Arsonval in 1881. But in the century since d’Arsonval’s work, the technical feasibility of ocean thermal energy conversion has been demonstrated on only **a** limited scale. The first plant was built and operated in Mantanzas Bay, Cuba, by d’Arsonval’s pupil, Georges Claude.

Claude’s model plant produced 22 kilowatts of electricity but required about 80 kilowatts of electricity y to run its equipment. [3] Nevertheless, it was enough to convince scientists and researchers during the subsequent 50 years that the oceans’ stored solar energy could be tapped by using the temperature difference between surface and deep waters.

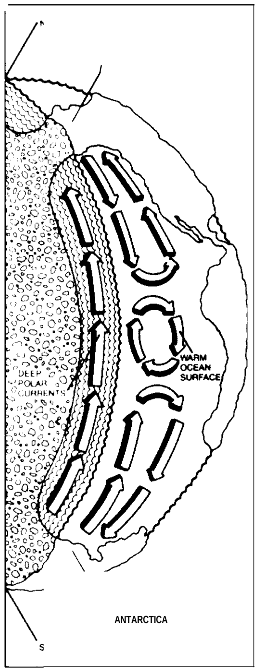
The Attractions of Ocean Thermal Energy

In the light of the fuel shortages and rising fuel prices of the 1970’s, the attractiveness of **ocean** thermal energy conversion is easy to understand: It offers an almost inexhaustible supply of fuel.

The oceans are massive natural storage basins for solar energy, so that the energy collected is available 24 hours a day. The natural collection and storage capacity of the oceans eliminate

[3]Georges Claude, “Power from the Tropical Seas, ” *Mechanical Engineering* 52 (December 1930): 1039-44.

problems associated with the sporadic availability of energy that marks most other systems for direct use of solar energy.



This around-the-clock availability makes the energy usable for base-load power, that steady stream of power that answers the routine needs of man. Further, of course, the Sun and tropical currents continue to warm the surface ocean waters while polar currents and other factors continue to chill the deep waters. Thus, there is a natural and dependable supply of the fuel— solar energy—and of the temperature difference used in processes for extracting the energy.

These characteristics, coupled with the expectation that use of the stored solar energy will be nonpolluting, make ocean thermal energy conversion attractive.

The Supply of Ocean Energy

There appears to be an abundant supply of this stored energy since the oceans cover more than **70** percent of the Earth's surface. However, the apparent vastness of supply can be misleading since only a very small percentage of the stored energy can be extracted.

There are a number of factors which limit the means of extracting useful ocean thermal energy. Initially, practical OTEC systems need to be located at very favorable sites. Some important site criteria are:

1. High thermal differences between the warm surface and the cold deep water,
2. Low-velocity currents,
3. Absence of storms (minimal wind and waves), and
4. Nearness to the market for the OTEC products.

The temperature difference between the surface water and deep water has the most significant bearing on extraction of ocean energy. As the temperature difference decreases the energy output will decrease drastically and the effective cost of each unit of energy will increase.

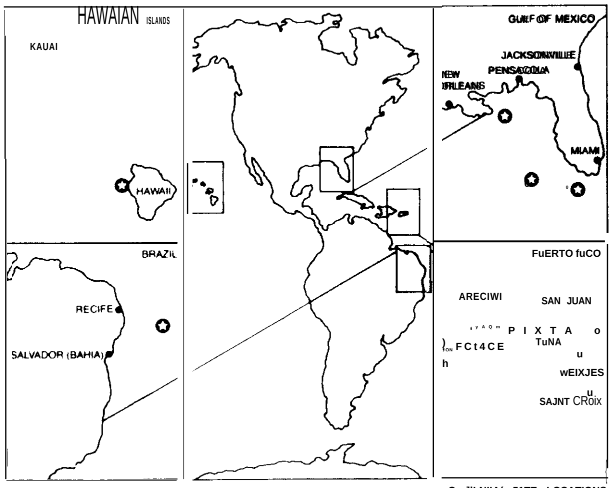
Current concepts for extracting ocean energy require **a** temperature difference of **330** to **400** F. With a temperature difference of **3**o° F, a plant would produce approximately 37 percent less output than with a temperature difference of 4o° F. With a temperature difference of less than 300 F, there is a marked loss of power output. For that reason, 300 F can be considered a minimum usable temperature difference to generate net power from a turbine. With a temperature difference of less than 150 F, there may be no net power output at all. That is, all the power produced would be consumed by the plant in running its own equipment and loads.[4]

Even a temperature difference of 40° F presents technical problems. For example, the technology proposed for OTEC designs uses standard heat engine cycles which are typical of those used in all powerplants when the heat from burning fuel is converted into electrical power. In conventional powerplants, temperature differences of hundreds or thousands of degrees are sought to get maximum efficiency. An OTEC design will attempt to create useful power from the temperature difference that is usually discarded as unusable in a conventional powerplant.

This temperature difference requirement means that most potential sites for ocean energy plants are in the tropics because the amount of solar energy absorbed by the surface waters of the ocean is greatest there. The best potential sites for plants to extract ocean energy are located within **200** of latitude north or south of the equator and along the routes of currents which carry warmed waters away from the equator.

There appear to be only two regions off the

4 Internal Memorandum to F. E. Naef from M. I. Leitnert Lockheed Missiles and Space Company, "Data for Sig Gronich, " Oct. 27, 1977, Sunnyvale, Calif.



General Site Location Map

continental United States which are promising sites—the Florida Gulf Stream and the Gulf of Mexico. Other areas of interest to the United States exist off Hawaii, Puerto Rico, the Virgin Islands, Guam, and Micronesia, but at least 37 other countries are closer than the United States to regions of the oceans where there are favorable thermal gradients. Table 1 is one of several available lists which identify countries which are most favorably located relative to potential OTEC sites. An attempt to identify all potential sites worldwide is now underway. Some estimates indicate that an amount of energy equal to about 3 percent of the current U.S. electrical production capacity could be extracted from a 200,000-square-mile section of the Gulf of Mex-

Table 1.—Countries Bordering Potential OTEC Sites
(Minimum distance from coast to suitable OTEC location for countries that border warm tropical waters)

	Distance, km
Countries bordering Indian Ocean (clockwise order):	
Madagascar	32
Mozambique	25
Tanzania	25
Kenya	25
Somali Republic	25
Southern Yemen	32
Muscat and Oman	6
Iran	32
Pakistan	32
India:	
West Coast	120
East Coast	65
Burma	75
Countries bordering Pacific Ocean (clockwise order):	
Hawaii	10
Mexico	25
Guatemala	32
El Salvador	65
Honduras	
Nicaragua	
Costa Rica	7
Panama	25
Columbia	25
Ecuador	25
Australia:	
Northeast corner	65
Otherwise	300
New Guinea	5
Java	5
Philippines	5
Vietnam	75
Sumatra	50

	Distance, km
Countries bordering Atlantic Ocean (clockwise order):	
SierraLeone	50
Liberia	50
Cote d'Ivoire	50
Ghana	50
Dahomey	50
Cameroun	65
Brazil:	
1°t020 South	15
Otherwise	100
French Guiana	130
Surinam	130
English Guiana	130
Venezula	3
Columbia	32
Panama	25
Costa Rica	15
Nicaragua	150
Honduras	24
Mexico	7
United States of America:	
Florida	1
PuertoRico	6
Cuba	2
Jamaica	2
Haiti	2
Dominican Republic	2
Guadelope(French)	2
Dominica(British [b])	5
Martinique(French)	2
St. Lucia(British[a])	2
St. Vincent (British[a])	2
Grenada(British [b])	2

[a]Distance to 5"C water at 500 meters.
[b]Freely associated with Britain.
SOURCE: LavL A. "Plumbing the Ocean Depths: A New Sourceof Powec" IEEESpectrum, 10, 22-27October 1973.

Table 2.—Power Potential of OTEC Plants at Some Potential Sites

	Area in square nautical miles	Power potential in MWe[a]	Percent of U.S. electric generating capacity[b]	Number of 500 MW OTEC'S required to produce potential power
PAC-I[c]	900,000	69,400	13.0	139
Micronesia.	3,000,000	231,400	43.6	462
ATL-I[d].	360,000	27,800	5.2	53
Gulf of Mexico.	200,000	15,400	2.9	31

a OTEC plant efficiency 1.5 percent; capacity factor = 75 percent.
bus electrical generating capacity = 530,000 MWe.
Physics Lab. study site
140° to 170" Long. East
20° to 30° Lat. North
d Applied physics Lab. study site
400 to 500 West Long.
5° to 15° North Lat.

NOTE: The estimates shown on this table area based upon an assumed gross power production rate of 2 MW/km². 2MW/km² is the additional solar radiation captured at the sea surface due to a temperature depression or anomaly created by the OTEC plant. This is the total thermal input to OTEC, not after conversion by OTEC, assuming that 200 MW/km² is the solar input to the surface. Two preliminary studies made by NRL estimate solar heat flux rate of 4.65 and 1.94 MWe/km² from heat added by solr re-radiation at two different tropical ocean sites. These heat flux rates were estimated on the basis of a 0.1 "C depression in the surface temperature of the water. (Data from *Ocean Thermal Energy Conversion (OTEC), Program Summary,* ERDA, Washington, D. C., October 1976. Also phone conversation with staff members of DOE, Washington, D. C., Jan. 23, 1978.)

In determining the amount of power which potentially could be generated and the number of 500 MW OTEC plants which would be used to generate that much power, the size of the temperature depression deemed acceptable is a critically limiting factor. Since there is currently much uncertainty about the effects of changes in the temperature of ocean waters, this chart uses a very small temperature depression. If a larger temperature depression is allowed, more OTEC plants could be placed in any given area and more-power could be produced

SOURCE: Office of Technology Assessment.

ice[5] while the equivalent of more than 43 percent of current U.S. electrical production capacity could be extracted from a 3-million-square-mile area in Mircronesia.[6] However, much of this energy is available at locations far at sea where there is currently no demand for it. In addition, to extract this much energy from these two areas alone would require about 500 ocean energy plants of the 500 MW size.[7] (See table 2.) Discussions about materials and equipment later in this text will indicate that it is not likely the United States would be able, during at least the next 20 years, to construct the amount of hardware, much of it larger than any powerplant equipment in existence today, which would be required to extract such large amounts of ocean energy.

A total assessment of the oceans' thermal resources and their relationship to the amount and kind of energy needed in specific places has not been made. However, the ocean energy which might be extracted is diffuse and making use of it will pose difficult technical and economic problems which are discussed later in this report.

The Status of Ocean Energy Extraction

The concept of extracting energy from the oceans has become known in the United States by the acronym OTEC—Ocean Thermal Energy Conversion. Funding of Government research on OTEC began with an $85,000 budget from

---

'L. C. Trimble, et al., Ocean Thermal Energy Conver*sion (OTEC) Power plant Technical and* Economic Feasibility *Technical Report,* Vol. 1, (Washington, D. C.: Lockheed Missiles and Space Company, Inc., April 1975).

'U.S. Congress, Office of Technology Assessment calculations.

'Ibid. (A 500 MW plant is half the size of a conventional nuclear powerplant.)

the National Science Foundation's Research Applied to National Needs (NSF-RANN) program in 1972. In **1975,** the research was transferred to the Solar Energy Division of the Energy Research and Development Administration (ERDA) which is now a part of the new Department of Energy (DOE).

Through fiscal year 1977, the Federal Government had spent about **$27** million 8 on OTEC research. The money brought proposals for several concepts to generate electricity for transmission to existing electrical grids onshore or to generate power to be used in the at-sea production of such energy-intensive products as ammonia, aluminum, or hydrogen. In fiscal year 1978, $35 million is budgeted for OT'EC research, most of which will be spent designing, building, and testing component parts of a prototype OTEC plant.

OTEC is still a research and development project. There is, as yet, no working OTEC plant; there is no working pilot model. But research is continuing and • quests for funds are growing, aimed at demonstration if the concept during the 1980's.

8 S . Piacsek, et al., Recirculation and Therrnoc/ine Perturbations from Ocean *Thermal Power Plants,* (Washington, D. C.: Naval Research Laboratory, 1976).

The Purpose of This Report

The future of OTEC research is now before the U.S. Congress, which must choose what level of support to give by annually appropriating funds for further research and development. Ultimately, Congress may be faced with questions about the regulation and operation of OTEC if it becomes a viable energy system.

To aid Congress in making its decisions, the following sections of this report will detail the current status of OTEC technology with particular attention to areas in which significant problems exist. They will also discuss the economic considerations which are pertinent to an OTEC system and outline economic problems facing some of the products most often suggested for OTEC production. The final sections of the report will deal with the present and possible future Government role in funding OTEC research.