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6. SOLAR SEA POWER
Ocean Thermal Energy Conversion

John M. and Kathryn Mervine Fowler

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INTRODUCTION

The world's largest solar collector is the sea, which makes up 70 percent of the Earth's surface. Enormous quantities of solar energy are collected and stored in the world's oceans. Scientists and engineers have long been intrigued by the possibility of harnessing this source of energy for humankind.

It has been understood, since the brilliant series of explanations and demonstrations of heat engines given by the French physicist Sadi Carnot in the 1820's, that mechanical energy can be extracted from the flow of heat energy between a hot and a cooler region.

An Ocean Thermal Energy Conversion (OTEC) power plant would operate a heat engine by utilizing the energy that can be made to flow between the warm solar-heated surface water of tropical and subtropical oceans, and the deep, underlying colder water. A working fluid, such as propane or ammonia, would be vaporized by the warm surface water, the pressurized vapor would turn a turbine, and the cycle would be completed by using the cooler water to condense the gas back to a liquid.

Over the past one hundred years, several small OTEC plants have been built. The idea was first proposed by D'Arsonval in 1881, but it was another French physicist, Georges Claude, who put the idea into practice. In the 1920's and 1930's, Claude built and tested several small experimental ocean thermal power plants.

After World War II, the French government formed a state corporation, Energie des Mers, to explore the possibility of constructing an OTEC power plant off the west coast of Africa. In the United States, the idea was raised again in the 1960's by the Andersons, a father and son engineering team, who calculated that the cost of ocean thermal energy would be competitive with existing energy technologies. The Andersons' work stimulated interest in this country, and the national solar energy program began funding OTEC R&D in 1972. The Energy Research and Development Administration (ERDA) FY1977 budget requested $9.2 million for OTEC programs.

There are certain problems to be overcome before this stored solar energy can be converted for use. The best sites for OTEC plants are in tropical and subtropical seas far from the population centers where the electric power is presently needed. It is possible, however, that the electricity can be converted to energy intensive products, such as ammonia, hydrogen, and aluminum, and these products can be conveniently shipped by sea.

The early tasks of research and development will be to test the basic components of OTEC plants and study their economic and technical feasibility. Then, if all goes well, we will see the operation of a floating OTEC power plant within the next decade.

An ocean thermal energy demonstration plant could contribute 100 Mw* of electrical generating capacity by 1985. It is estimated that OTEC could

* See Glossary for definition (Fact Sheet 18).

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produce 20,000 Mw or more by the year 2000. Present U.S. electrical production capacity is almost 500,000 Mw.

RESOURCES

Each year the sun bombards the Earth with about 18,000 times as much energy as man consumes. Since 70 percent of the Earth's surface is water, much of this energy goes into heating the surface waters of the tropical oceans. It also melts the ice caps which surround the North and South Poles, creating the deep cold ocean currents which flow toward the equator beneath the warm upper ocean layers. It is this temperature difference which is the potential source of OTEC energy.

A most productive area for the OTEC idea is found between the tropics of Cancer and Capricorn, where 90 percent of the Earth's surface is water and the solar radiation input is large. The ocean surface temperature in this region remains very close to 80°F all year, and the underlying flow of water away from the polar ice caps keeps the deeper water at a temperature of about 35°F. An OTEC plant would produce work from this nearly 50°F temperature difference. The amount of stored energy in this large ocean expanse is substantial. The Gulf Stream, for example, carries nearly 1,500 million cubic feet per second of near-tropical seawater through the Gulf of Florida off Florida's Atlantic Coast.

The stream flows in a path about 20 miles wide and 500 miles long. It has been estimated that OTEC units spaced a mile apart, along the length and width of the stream and operating at net efficiency of only 2 percent, could produce 26 x 10^{12} kw-hr per year--15 times the total U.S. consumption of electric power in 1975.

The resource base, as is the case with most forms of solar power, is not the limiting factor. What keeps us from tapping this large source is the need for appropriate technology. This subject will be discussed in the following section.

TECHNOLOGY

The operation of an OTEC plant offers no serious scientific challenge; its basic processes are well understood. Just as a fossil fuel plant runs on hot combustion gases, the OTEC plant runs on heat from the ocean. In both plants there is a "working fluid": The fossil fuel plant uses steam and the OTEC system uses a fluid with a lower boiling point, like propane or ammonia. In both plants the working fluid must be cooled after it has expanded and driven the turbines. The cooling is frequently provided by a nearby body of water for the fossil fuel plant, and by the deeper ocean layer for the OTEC plant.

A simple description of what might happen is the following: Ammonia would be boiled by the warm surface water, creating a gas at a pressure great enough to turn a turbine (which provides the motive power for an electric generator). The spent gas is then cooled back to a liquid in a condenser by cold water pumped from the depths, and the cycle is repeated. The efficiency of a heat engine depends on the ratio of the difference between the intake and exhaust temperature to the intake temperature (temperatures must be expressed in absolute degrees). The ideal efficiency of a heat engine operating between 80°F of the surface and 35°F of the deeper layers is only about 7 percent. Actual net efficiencies will only be about 2 or 3 percent. It is only the fact that the thermal energy is freely available that makes conversion at such low efficiency thinkable.

While no large plants of this type have yet been built, there is considerable ocean engineering experience to draw upon. Recent developments in underwater technology associated with offshore oil rigs, naval undersea activities, and deep-ocean mining will all contribute.

In preliminary design, an OTEC plant might be built on a large floating platform measuring perhaps 400 feet in diameter and extending several hundred feet down into the water. The pipe which brings the cold water from the depths would be 45 feet or more in diameter and 2,000 to 3,000 feet long.

The fact that the "boiler" will be at low pressure (150 psi vs. 1,500 psi in a steam plant) and that turbine speeds will not be very high should ease the requirements on materials and make for simple maintenance. The corrosiveness of seawater and the possibility of marine growths fouling and clogging the heat exchangers and pipes are problems to be met. The plants will have to be dynamically positioned or moored, and be strong enough to withstand storms.

One of the most significant advantages of the OTEC idea is that the solar energy is already stored in the water as heat and is continuously available. Thus, the difficulty of the intermittence of most solar conversion systems is avoided. There is a different kind of storage problem, however. The long distance between these plants and population centers will make it necessary either to transmit electric power through submerged cables or to use the electric power at the site to create products that can be transported by ship or barge. It has been suggested, for instance, that hydrogen could be generated by electrolysis of seawater or that ammonia (for fertilizer) could be produced using the hydrogen from water and the nitrogen from air. It may also be feasible to locate electric-intensive industries (such as aluminum manufacture) near the plants, as is currently done with some conventional power plants.

The ERDA program is concentrating on the design, construction, and testing of the components and subsystems and on the planning of storage and delivery systems. A prototype OTEC plant of about 25 Mw is expected to be built in the early 1980's for further testing. The first commercial demonstration plant is expected to be about 100 Mw in capacity (and to consist of four 25 Mw modules); the optimum commercial size may be as large as 500 Mw.

ECONOMICS

The future of the OTEC concept will be determined by the competitive costs of the electricity and other products it provides. At the present stage, it is difficult to produce convincing cost estimates. But Clarence Zener, a physicist at Carnegie-Mellon University in Pittsburgh, has provided some estimates based on further refinement of the Andersons' earlier work. At 1975 prices and using current technology, he quotes $2,100 per kw capacity, or about 50 mills per kw-hr, which is about twice the cost of nuclear and coal-fired plants.

He points out, however, several areas in which cost reductions are expected, including considerable savings in the design of the heat exchangers (the system which transfers heat from the water to the working fluid) and the condenser. The most interesting possibility for cost efficiency is to locate a large number of these plants in the tropical oceans. Conventional power plants, fossil fuel or nuclear, are built to individual specifications and cannot take advantage of mass-production techniques. Each is unique in its siting, its environmental safety problems, its power rating, etc. The location of the OTEC plants in a common environment should make it possible to mass produce their components--to build them all to one set of specifications. This would not only reduce the cost of the parts, but would reduce the overall costs even more by shortening the construction time and thus reducing the interest costs on the borrowed money. Zener estimates realistic costs of about $500 per kw in the 1980's. At this cost, one could transmit OTEC electric power 100 miles at costs competitive to those for nuclear generation of electricity.

ENVIRONMENTAL PROBLEMS

It is even more difficult to anticipate environmental problems associated with OTEC plants than to estimate the economic factors. Compared to coal-fired or fission plants, however, the environmental impact should be fairly benign.

A long-term concern of a successful and large-scale OTEC program is the effect of a possible change in the temperature characteristics of the tropical ocean. Climate changes can be influenced by changes in atmospheric or oceanic temperatures, but there is little evidence as to how serious a given change in the surface temperature would be. This is an important area for further study. However, it is a distant concern since generation of the entire electrical requirements of the U.S. from the thermal energy of the Gulf Stream would cause a drop of only a fraction of 1°F.

There are both potential advantages and disadvantages associated with pumping large quantities of cold water to the surface. These waters are rich in nutrients and might, therefore, allow the establishment of fisheries around the plants. The practice would definitely distort the ecological balance, and the new balance must be anticipated and understood. In particular, it will be important not to disrupt the natural life cycles of oxygen-producing algae.

The cold water, however, also contains large amounts of dissolved carbon dioxide which would be released upon warming. Preliminary calculations show that the production of 1 kw-hr of electricity by an OTEC plant would release about one-third as much carbon dioxide as released by the present burning of fossil fuel for the same purpose. Since the change in atmospheric temperature due to the "Greenhouse Effect" brought on by increase in atmospheric CO_2 is one of the long-term outcomes, continued study and a search for ways to lower this effect of OTEC plants will have high priority.

SUMMARY

The technique of converting the ocean's thermal energy into electrical energy is one that is understood in theory but not as yet fully tested in practice. Some significant adaptations of and improvements in presently available technologies will be needed in order to satisfy the specialized requirements of this new application and to achieve minimal and competitive costs. Important savings are anticipated from mass production.

An objective of the ERDA research program is to design, construct, and test the components and subsystems and to construct a pilot plant of about 25 megawatts in the early 1980's. During the course of this development, special attention will be given to problems of corrosion and biofouling, and to the design of the special heat-exchangers which are needed. Methods of delivering the electrical energy and/or of storing and transporting energy-intensive products will be studied, and the environmental impact will be analyzed in detail. Legal and jurisdictional considerations associated with the operation of floating ocean thermal power plants need to be resolved.

The major turning points for the development of the ocean thermal system will be the decision to construct the 25 Mw floating power plant, and the decision to enlarge the plant to a 100 Mw demonstration power plant. The decision on whether to construct land and sea test facilities will be made by 1977. Based on those results, ERDA will determine early in the 1980's whether or not to construct the 25 Mw floating prototype power plant. And, by the mid 1980's, the decision will be made on whether to construct the four advanced power modules in order to convert such a prototype plant to a 100 Mw demonstration plant.

Federal funding for the OTEC program has gone from $700,000 in FY1974 to $6 million in FY 1976, and is projected to go to nearly $47 million in 1980 if the demonstration plant is approved for construction.

The future levels of funding and the anticipated contribution of this source of energy depend on the successful completion of the preliminary steps described above. If all tests prove out successfully, a 100 Mw plant may be operating in 1985 and mass production may be underway. If the tests are negative, or the money needed for testing and development is not forthcoming, this exciting idea may simply remain on the drawing board. In either case, the knowledge gained in OTEC research may contribute to the development of other technologies (e.g., the thermal discharges of conventional power plants) and the ocean's thermal energy will remain to tempt the engineer and the dreamer.

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