RESEARCH NEWS

Ocean Thermal Energy: The Biggest Gamble in Solar Power

Among the various systems proposed for utilizing solar energy, the largest and most complex one would use ocean water temperature differences to generate power.

Because the amount of energy that could be captured from the warm tropical oceans is truly phenomenal, the ocean thermal energy concept has many proponents. The ocean itself would be the collector and energy storage medium, eliminating the need for two of the costliest components of land-based solar thermal systems. Drawing in warm water from the surface and cold water from the depths, an ocean thermal plant could operate continuously 24 hours per day. For this reason, the ocean thermal concept has often been characterized as the only sort of solar system with the potential to provide base-load power.

This is the last in a series of seven Research News articles examining recent developments in solar energy research.

Having identified a unique role for the technology, government solar energy planners put together a rapidly growing program for ocean thermal energy conversion (OTEC), which is moving quickly into demonstration projects. Yet the shape and scope of the program have been determined less by solar energy administrators than by the two large aerospace companies eager to develop the concept (Lockheed and TRW), according to many observers. From $8 million 2 years ago, the budget has risen to $35 million in fiscal 1978, or about one-fifth the funding for all solar electric technologies. But electric utility companies have shown little enthusiasm for the concept and recently there has been criticism of the program's direction as well. In the words of one prominent ocean engineer, the effort appears to be going "too far too fast for what may be a tiny payoff at great price."

According to a recent review conducted by the National Academy of Sciences, the OTEC concept is technically feasible if enough money and time are spent on the project, but many critical problems remain to be solved. The review panel* found that OTEC was a long-term energy option, that the projected cost estimates were "very optimistic," and that there had not been sufficient evaluation of alternative types of OTEC systems to justify the present program direction. In short, the conclusion was that the task will be harder, slower, and costlier than OTEC advocates suspect. The panel, which included a number of marine researchers and engineers, did not, however, recommend ending the program.

Similarly robust and open-minded skepticism has been displayed by the national research arm of the electric utilities, the Electrical Power Research Institute, which has a $20-million, 5-year solar program but does not support any OTEC work. "We are concerned that the numbers put out seem pretty optimistic," says the coordinator of solar thermal programs, John Bigger. "We looked at the risks and decided to watch the program for now," he says. Another reason utilities are skeptical is that possible sites for OTEC are not nearly as abundant as they are for other solar technologies. Potential sites off U.S. shores are basically limited to the Gulf Coast and the lower eastern coast of Florida (although Hawaii, Puerto Rico, Singapore, Brazil, and Mexico would be ideal sites, according to a recent study by the National Science Foundation).

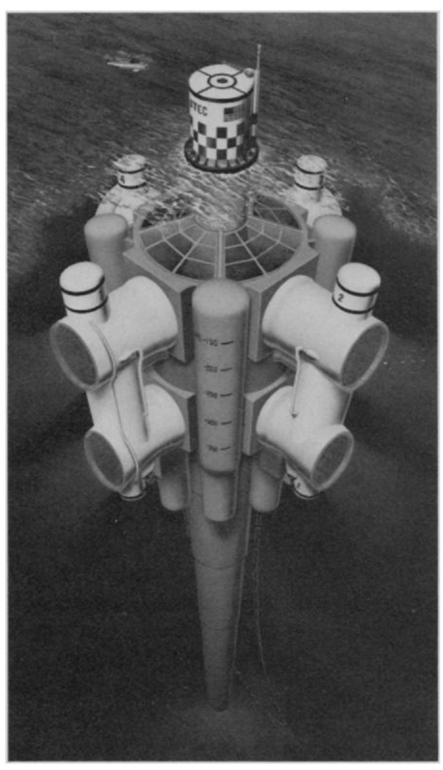

Fig. 1. The Lockheed OTEC concept.

Having one of the few choice locations in the country, the Florida Power & Light Company has studied OTEC perhaps more than any other utility and found the arguments for it wanting. "The utilities today are faced with a high risk world but, relatively speaking, the current concepts for OTEC are really high risk," says FPL's coordinator for research and development, David Jopling. He thinks the concept faces six to ten major technological ceilings. "Perhaps it is not impossible," he says, "but they just don't know what they are up against." Jopling, like the Academy, however, does not wish an end to OTEC. Instead, he observes that "the best promotion for the project right now is a healthy realism."

What OTEC is designed to accomplish is generally acknowledged to be the toughest problem—thermodynamically speaking—in the energy field. The temperature differences that are available between surface and deep waters in tropical latitudes are only 34° to 44°F. At such temperatures, an ideal heat engine would have an efficiency of 6 percent, and in practice OTEC will not achieve more than 2 or 3 percent efficiency. Such a meager performance rating requires that a plant draw in enormous amounts of seawater. A 100-megawatt plant would have to pump through 100,000 gallons per second—approximately as much as flows through Boulder Dam.

It takes energy to move water around, and the pumps on an OTEC station would consume 30 percent of the gross power output of the plant, according to the engineering design studies done for the government program. Such an energy balance is scandalously poor by the standards of present-day generating plants, which typically use less than 1 percent of their power for internal needs. Any slippage in the performance of the plant heat exchangers could make the OTEC energy balance even worse, and a thin layer of marine slime on the heat exchanger surfaces could push the energy balance into the red.

"Performance calculations have been based on optimal conditions which could

*The review was conducted by a 12-member panel acting under the auspices of the Marine Board of the Assembly of Engineering of the National Academy of Sciences, chaired by Herman Sheets of the University of Rhode Island.

be downgraded by any number of known and unknown effects," says the Academy review. In a recent speech given to the American Institute of Aeronautics and Astronautics, Jopling questioned whether the present OTEC designs have the ability to produce "any net energy for any appreciable length of time." The proponents of the concept are counting on the plants to operate satisfactorily with virtually no shutdowns for 20 to 40 years.

A number of different OTEC designs have been proposed. A team headed by Lockheed suggested that the plant be a submerged sparbuoy (Fig. 1) to make it safe against hurricanes. A team headed by TRW suggested a floating top-shaped plant, and a group headed by the Applied Physics Laboratory at Johns Hopkins designed a rectangular plant-ship (Fig. 2) that would move slowly under its own power and have factories for electrochemicals and electro-metals, such as ammonia and aluminum, on board.

These designs have in common the fact that the plant would be built of reinforced concrete and would displace as much water as a supertanker. Suspended from the bottom of each vessel would be a pipe for taking in cold water, as much as 30 meters in diameter and up to 750 meters in length. The Johns Hopkins design, which is intended to develop an OTEC system as rapidly as possible by using standard components wherever possible, would use 20 pumps as large as anything available today to draw in cold water. Twenty more pumps would draw in warm water through near-surface intakes. The Lockheed and TRW designs call for far larger pumps.

The water pumps would deliver seawater to two sets of heat exchangers. The warm-water heat exchanger would evaporate a working fluid (probably ammonia), which would produce a low-pressure gas to power a (custom-designed) electric turbine. To complete the thermal cycle, the ammonia would pass through a cold-water heat exchanger and be condensed back to a liquid.

Enormous heat exchangers will be required. As projected now, the surface area would cover as much as 700,000 square meters. The size depends on performance, which is generally recognized to be a crucial question for the OTEC program. (The government program, administered by the Department of Energy as of 1 October, has issued a $3.5-million contract to TRW to test a 1-megawatt heat exchanger on the old Howard Hughes–CIA special equipment barge.) If the heat exchangers are built of cheap aluminum, corrosion could be a severe problem, according to the Academy review. If they are built of expensive titanium, one OTEC plant would exhaust the entire annual national production.

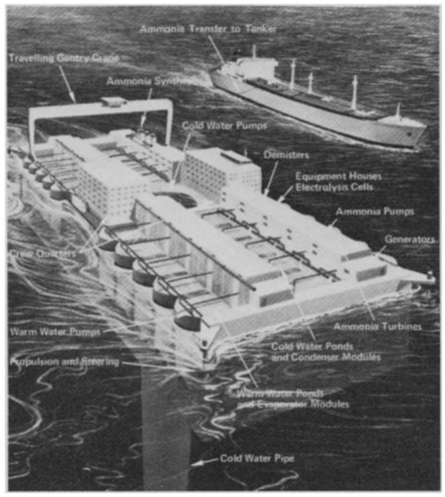

Fig. 2. A self-propelled OTEC plant-ship proposed by the Applied Physics Lab of Johns Hopkins University.

Any slippage in heat exchanger performance would degrade the entire thermal cycle. This is a concern, first because the heat transfer coefficients that have been assumed in designs are superior to those used in present seawater practice, according to Herman Sheets. Second, the problem of the fouling of marine hardware by slime growth has been studied extensively by industry, academia, and the military with only marginal success. Experiments conducted so far in the OTEC program indicate that only ¼ millimeter of slime would reduce the plant's performance by 60 percent. Slime grows slowly for the first 10 weeks, according to John Fetkovich at Carnegie-Mellon, but the rate may be faster in some ocean areas than others.

There appears to be no practical way to prevent slime formation, so it would have to be cleaned off—probably weekly on the basis of available data according to Sigmund Gronich, who is head of the government program. Various types of brushes and water jets have been considered, but thorough studies have yet to be made of the cost of cleaning the huge heat exchangers.

Other problems must be solved as well. No one has shown that it is possible to moor anything the size of an OTEC plant in the current of the Gulf Stream, and no one has tested the stresses that will be put on the huge cold-water pipe by plant motion, currents, water intake effects, and internal turbulent flow. Very little study has been made of the problem of leaks in the heat exchangers, although abundant small leaks over such a large area could be a huge problem. Finally, little consideration has been given to the reliability of the plant. Many problems, ranging from failure of the underwater transmission lines to ruptures of plumbing, or corrosive failure of key components, could shut down the plant. But the design studies fix a price of electricity or products based on the very optimistic estimate that the plant will operate at full power at least 90 percent of the time—a far better performance record than most land-based plants have.

Whenever shutdowns did occur, OTEC plants would face another type of fouling problem. As soon as water flow stopped for a few days, barnacles would attach to heat exchanger surfaces, according to Fetkovich, and would keep growing after operations resumed. The cost of debarnacling a whole OTEC system that accidentally became encrusted can only be guessed.

The design studies project that an OTEC plant will initially cost $1500 to $2500 per kilowatt, not counting the expense of getting electricity to shore or of building industrial plants on board. These costs are based on incomplete data, however, according to the Academy panel. Some components, such as the cold-water pipe, dwarf any marine structure that has ever been attempted. The review panel found that OTEC plants will be similar in many ways to the huge North Sea oil-drilling platforms (Condeep and Ekofisk), which have run into technical difficulties and finally cost 2 to 2.5 times what was expected. The significant point raised by many critics is that systems built for the marine environment cost many times what the same system would cost on land. "The estimate of $2500 per kilowatt is the best that I've seen," says Jopling, "but it could be off by a factor of 5."

Many energy specialists applaud the basic studies that will provide the underpinnings of the OTEC program because these studies could lead to improved ways of using the enormous amounts of low-grade heat that are now wasted. Many power plants located on ocean coasts have sources of both hot and cold water with temperature differentials (20° to 30°F) only slightly less than the OTEC ideal, and the government's uranium enrichment plants provide heat at temperature differentials equal to or greater than those at the best OTEC sites. Many critics ask why we should rush to the sea when OTEC technology could certainly be tested more cheaply on land, and might provide cheaper power when used as a bottoming cycle on present plants. The advocates reply that no one will seriously consider investing in an OTEC plant until a true oceangoing prototype is demonstrated.

The OTEC program is scheduled to include three steps leading to a commercial-sized demonstration, now nominally set at 100 megawatts. A 5-megawatt pilot plant is due to be contracted late next year, followed by a 25-megawatt version and finally a commercial prototype, scheduled for installation in 1984. The managers at the Energy Research and Development Administration think that all the problems pointed out by the critics have been recognized and addressed by the program. "We think it is an aggressive program that has set out specific review points based on the experiments necessary before proceeding to larger hardware," says Gronich. Whereas the Academy panel was under the impression that the design of the 100-megawatt system would begin this year, it will actually start in 1980 and "that is a big difference," according to Gronich.

Why is the program moving so rapidly when the burden of the technical criticism is that optimum performance from every subsystem is critical to successful operation? Why have such basic questions as how much power will be available at various distances off shore and whether and at what cost that power can be transmitted back (when undersea transmission experience is limited to rather short distances and minimal depths) not been addressed? Why such urgency to develop at great cost a solar resource which the United States has only in limited supply? Who will own and operate the plants? These questions bother not only utility executives but some solar energy advocates as well. Deploying an OTEC plant will almost certainly require more centralized institutional structures than the present array of independent utilities, which have made it clear that they will not invest in research now and are skeptical about buying the system later.

To keep on its ambitious development schedule, the OTEC program will have to grow rapidly. The longer the task takes the more it will cost. The federal investment in ocean thermal systems could easily begin to match the multibillion dollar investments that have been made in developing nuclear power—an enterprise designed to produce a product of similar size and complexity. The gamble with OTEC is that for technical reasons alone it may provide very little energy.—WILLIAM D. METZ

Elementary Particles: Classical Mechanics to the Rescue?

"Getting back to basics" has been one of the more fashionable ideas recently in several segments of society. A variation of the same theme is making headway in the arcane world of those theoretical physicists trying to construct models of elementary particles.

The problem for theorists attempting to solve equations describing the largest class of elementary particles, the hadrons, is that these nonlinear differential equations are too difficult to solve with existing mathematical tools, even when the equations represent what physicists call the simplest theory with a chance of actually describing the real world. One recently popular approach to this problem has been to study the classical mechanics analog of the quantum mechanical theory. (The resulting equations are not completely classical, however, in the sense that they are still subject to the constraints of special relativity.) The expectation is that classical solutions will provide theorists with the necessary insight to attack successfully the fully quantum mechanical problem.

Investigators following this line of thinking have already found some hitherto unsuspected aspects to their particle theories. Now theorists are hoping that the solution of the classical equations will eventually lead them to quantitative descriptions of the hadrons, including their masses and the strengths of the interactions between them. Whether classical mechanics will ever lead to such successes is problematic, for the history of elementary particle theory is littered with the relics of once promising, but now discarded, theoretical approaches. At present, however, observers seem confident that, even if classical mechanics does not lead directly to experimentally verifiable results, many of the pertinent concepts will survive to be incorporated into future theories.

An extra bonus has been the discovery that the classical equations developed by particle theorists consitute a subset of a larger class of equations that has been studied in detail by mathematicians for altogether different reasons during the last 30 years. What appears as a fruitful cross-fertilization of the two groups of investigators is now under way because it turns out that solution of even the classical equations poses formidable difficulties.

The equations belong to the class of theories called field theories. A field is simply a quantity (scalar, vector, or even tensor) whose values at each point in a coordinate system describe some effect. The electromagnetic field derived from Maxwell's equations, which happens to be a vector field, is probably the most familiar example. That the equations used to model the hadrons might be difficult to solve is perhaps preordained by the complicated name for the type of field theory from which they come: non-Abelian gauge theory. The non-Abelian gauge theories under discussion, which are vector field theories, also go by the name Yang-Mills field theories, after Chen Ning Yang of the State University of New York at Stony Brook and Robert Mills of the Ohio State University, who formulated them in 1954.

The current candidate Yang-Mills field theory is called quantum chromodynamics; the name follows in part because the theory is a generalization of the most successful quantum field theory yet developed, quantum electrodynamics. However, quantum electrodynamics describes only the interactions between electrically charged particles by way of the electromagnetic force, and the charged particles that are most satisfactorily treated are the electron and its antiparticle, the positron.

Elementary particles known as hadrons are so classified because they can interact by way of an altogether different force called the nuclear strong force. The best known examples of hadrons are the proton and the neutron. At very short distances characteristic of the dimensions of nuclei themselves, the strong force dominates all other types of interactions that hadrons can also experience, such as the electromagnetic. The strong force is much more complicated than the electromagnetic, and the resulting quantum field theory is likewise much more complex. Over the years, physicists have successfully combined the results of experiments at ever larger accelerators with studies of the sym-