ISETAP is alive and well. I look forward to my continued role as chairman of ISETAP and to working with state and local government officials through ISETAP to help bring the benefits of science and technology to bear on the problems of states, counties, and cities.

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The panel was in fact abolished by the reorganization plan as a congressionally mandated arm of the Office of Science and Technology Policy. Its reappearance in another form is reassuring. What counts is that Press evidently intends to seek results.—W.D.C.

Solar Energy: The Prospects for OTEC

The Research News article on ocean thermal energy conversion (OTEC) by William D. Metz (14 Oct., p. 178) discusses an important renewable energy source for the United States and the world. We feel that it gives an unnecessarily pessimistic appraisal of the prospects for OTEC as a commercially competitive, base-loaded (24 hour a day) source of electric power. As an industry participant in the Department of Energy OTEC program, we are convinced that a 100-megawatt OTEC demonstration plant can be operating by about 1985 and that OTEC can supply a significant part of U.S. electric power at affordable rates by the year 2000.

Much of the information in Metz's article is drawn from a recent review of OTEC by the Panel on Ocean Thermal Energy Conversion of the Assembly of Engineering's Marine Board. The panel review is explicitly based on information available through December 1976, and several of the technical questions that it raises are in the process of being answered—most notably the fear that biofouling would bring OTEC operation to a quick halt. The Department of Energy is also taking steps to remedy the management deficiencies noted by the panel.

The Marine Board panel does not question the technical feasibility of OTEC, merely the time scale of development and the economic viability of the commercial OTEC plants. It is true that there are engineering problems to be solved and that OTEC may not be fully competitive until second or third generation hardware is available. This is true for all solar energy technologies; otherwise, there would be no need for government support of an engineering development and demonstration program. In the particular case of OTEC, the world's basic heat source (the sun) and its largest heat sink (the ocean) are being used to drive what is basically a 1920's-vintage ammonia refrigeration plant. Only the scale of the plant is unfamiliar. The machinery operates at constant load in a benign environment, never seeing more than 85°F—much pleasanter conditions than most land-based utility plants. The engineering problems of designing large structures at sea, in terms of both construction and longevity, are being answered daily by the offshore oil industry and by supertankers. Testing on land would be less economical than testing in the sea environment, since the ocean resource must be brought to the land site and returned to the sea; the consequent piping and pumping requirements are not trivial (*1*).

The Marine Board panel commented unfavorably on the Rankine efficiency (about 3 percent) of OTEC and did not mention the State of Oregon technique of net energy assessment (*2*). By this technique, energy sources are evaluated in terms of the total net input to produce 1000 calories of usable energy output. The input includes the energy required to build the plant, obtain the fuel, and transport it to the plant site. An OTEC plant (*3*) will use an uncontrollable, renewable resource delivered free at the site. It will require about 700 calories of controllable energy to produce 1000 calories: a *positive* net energy balance. Fossil and nuclear plants require about 3500 calories for 1000 calories produced, a large negative balance. The Rankine efficiency does have a bearing on the economic performance of OTEC, but the value is acceptable. In fact, the hydroelectric plants with which the public utility industry is familiar have a considerably lower Rankine efficiency when one considers the total thermal process, starting with the evaporation of water.

In our opinion, Metz's article should not have left the impression that OTEC is a distant and perhaps unattainable "gamble." We agree that the issue should continue to be debated. We hope that future discussions will be based on a more balanced presentation of the technical and economic issues.

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The Research News article by Metz on ocean thermal energy conversion gives a distorted view of the potential value, status, and prospects of the OTEC program. OTEC offers a truly phenomenal energy resource at low risk and low cost compared to heavily funded programs for development of advanced coal and nuclear technologies, which pose basic scientific, engineering, and environmental problems. At a time when the technical community is generally critical of the government for making endless studies and taking little action to forward the development of new energy sources, it is surprising to find an article in *Science* that gives so much credence to criticism of the Department of Energy (DOE) for moving at a modest rate in a step-by-step program to test component and system designs, resolve engineering problems, and provide an in situ OTEC pilot plant demonstration within a reasonable length of time. Fortunately, DOE and Congress are providing the incentive and funding to proceed with the OTEC program in a timely fashion.

We vigorously object to the suggestion that Lockheed and TRW, rather than the Solar Energy Division of DOE, are running the program. Lockheed, TRW, the Applied Physics Laboratory (APL) at Johns Hopkins, and other participants in the program not mentioned by Metz are all working on OTEC under DOE direction in close cooperation with some of the country's most experienced marine engineering design and heavy construction companies. Their in-depth evaluations have all led to the conclusion that OTEC is technically feasible and that its cost will be comparable with that of coal and nuclear power plants.

The latest estimates by TRW (*1*) and by Lockheed (*2*) of electric power production from offshore fixed OTEC installations are in the $1100 to $1500 per kilowatt range (in 1975 dollars). No estimate based on the most recent studies has been as high as $2500 per kilowatt. With estimated costs of power transmission to shore included, it is projected (*3*) that offshore OTEC plants will deliver power to the southeastern United States at 30 to 40 mills per kilowatt-hour before 1990.

The APL concept (*3*) of an OTEC plant-ship cruising so that it remains in the warmest waters of the tropics offers several important cost advantages over offshore siting: (i) higher average temperature differences, which increases net power by about 30 percent; (ii) avoidance of the costs of mooring or dynamic positioning; (iii) simplification of platform design and reduction of cost because of the absence of hurricanes and major currents at low latitude; and (iv) replacement of power transmission costs by lower product shipment costs. These advantages would permit on-board power to be produced at 9 mills per kilowatt-hour and ammonia to be produced and delivered to the United States at a cost of $100 per ton (in 1975 dollars, F.O.B. New Orleans). Ammonia is now made from natural gas, our scarcest fossil fuel. In addition to essential fertilizers, OTEC-produced ammonia could provide an effective means of transporting and storing hydrogen. The hydrogen could be readily generated from ammonia in situ and used in fuel cells to produce nonpolluting electric power anywhere in the United States. We estimate (*4*) that the cost of generating electricity in this way by about 1990 will be 28 to 42 mills per kilowatt-hour (in 1975 dollars).

Two additional implications in Metz's article require correction:

1) No experience indicates that ¼ millimeter of slime growth on marine hardware would reduce OTEC performance by 60 percent. Experiments by Fetkovich (*5*) show a biofouling buildup in 12 weeks that would reduce performance of the APL heat exchanger by only 18 percent. However, our baseline performance evaluation already assumes this degree of fouling. A cleaning system design has been tested recently which offers a practical method of weekly removal of biofouling accumulation (*6*).

2) Estimates by the APL of the OTEC platform cost are based on delivered costs of reinforced concrete structures, for example, the ARCO barge, not on preliminary estimates of those costs. Therefore, these estimates are not subject to the large uncertainties mentioned in the article with respect to the construction of North Sea oil-drilling platforms.

Utilities are understandably reluctant

to promote developments which disturb their present favorable institutional arrangements, but DOE's mission is to create additional energy sources. Industrial interest in producing ammonia by means of OTEC also provides an immediate impetus to proceed with a pilot plant. If OTEC proves cost effective, as current studies indicate, an investment comparable to the current investment in nuclear power would be more than justified. As Metz observes, "The longer the task takes, the more it will cost." So let's get on with it!

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I have enjoyed the series of excellent Research News articles on solar energy. In this field, the major point of debate is invariably economics. Such debates often leave the reader puzzled as to what or whom to believe. I would like to point out that cost *comparisons* are often easier to make (and believe) than cost estimates. Taking the proposed ocean thermal energy conversion (OTEC) power plant as an example, one could compare its cost goal to the cost of an existing land-based, coal-fired power plant using an equal amount of thermal energy. Modern power plants are about 40 percent efficient at converting thermal input to electricity. OTEC, on the other hand, would have an efficiency of 2 percent or less. In both cases, the cost of electricity is dominated by amortization of the capital investment. To a first approximation, then, the cost of a competitive OTEC power plant would have to be 20 times less than the cost of an equivalent land-based power plant.

At present, the cost of mining and transporting coal contributes about 25 percent to the cost of electricity. Under the kindest assumption, the equivalent "fuel cost" of OTEC can be taken to be zero. This reduces the capital investment ratio that OTEC is up against to $0.75 \times 20 = 15$. From this point of view, then, it appears that OTEC supporters claim to be able to build and maintain a floating or submerged power plant that would be 15 times cheaper than a land-based power plant.

In view of the implausibility of such a scenario, it is disconcerting to see one-fifth of the Department of Energy's solar electric budget allotted to OTEC, when other much more promising approaches receive little or no support.

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Concerning an issue as controversial as the OTEC program, there are few observers on the middle ground. The foundations for the present program were laid by the large ocean-engineering groups at Lockheed and TRW at a time when the technical strength of the OTEC program office was quite limited. In fact, until late 1976, the OTEC office had only one professional staff member. In the circumstances, the Energy Research and Development Administration called upon the outside services of the Marine Board for a program review. The review panel included a director of the Scripps Institute of Oceanography, an official of a major offshore drilling company, a Westinghouse steam turbine expert, an authority on marine heat exchangers who worked on the submarine *Nautilus*, and engineers from several universities. The panel was well qualified and well balanced in its institutional origins. It found the OTEC concept attractive but the implementation subject to "many critical problems." The cutoff date for the panel's extensive literature search was December 1976, but it is hard to outdate the status of a 50-year-old technology in a few months.

With respect to the specific points raised by Avery, the statement about the effects of ¼ millimeter of slime fouling was checked with Fetkovich before publication, and he agreed it was a fair characterization. The relevance of the ARCO barge is obscure. There is no concrete barge in the Lockheed or TRW design, and in the Johns Hopkins design the barge contributes only 25 percent of the projected cost of the system. Heat exchangers alone cost significantly more. The unpredictability of OTEC economics comes from the many components of uncertain design that have never been built before.—W.D.M.