We agree with Hall and Crouch that the effective ΔT loss (T is the absolute temperature) associated with removing heat from water must be included in any detailed analysis of a real thermal energy conversion system, along with many other thermodynamic, economic, and environmental considerations. We strongly disagree, however, that inclusion of this ΔT loss necessarily reduces the achievable head (for a thermocline temperature difference of 15°C) to about 16 m. The actual effect depends on the system design and heat engine performance.

Apparently, Hall, Crouch, and we agree that the net available equivalent head (in meters) (for the example of a 15°C temperature difference) is given by 320f, where f is the system efficiency as a fraction of the theoretical maximum (*1*). We maintain that f depends on the system design and is not limited by fundamental thermodynamic considerations to 1/20 [the value obtained by Hall for the Ocean Thermal Energy Conversion (OTEC) Rankine system does provide a base line, and it is up to anyone proposing an improved system to show that an $f > 1/20$ (or some other advantage) can be achieved.

The OTEC system was designed to optimize the ΔT allocations so as to minimize the capital cost per unit power produced, and ". . . the cost and performance of heat exchangers dominate system economics . . ." (*2*). This optimization, for the OTEC Rankine system, requires that the source and sink water flow through massive heat exchangers once, and any remaining heat is discarded. The OTEC studies convincingly show that this system will reduce the net output, for a total ΔT thermal source of 15°C, to ~ 16 m of equivalent head. (Even with this limitation, the thermocline resource would provide a significant new power source.) However, this result is not fundamental, and the minimum cost design for systems that use non-Rankine heat engines will call for different values of f. For example, the Nitinol heat engine, to which we referred in (*1*), utilizes a solid metallic alloy as working medium. The working material is corrosion-resistant and can be placed directly into contact with the hot and cold water, and the resistance to heat transfer per area between water and Nitinol is much less than that for water-heat exchanger-working fluid for the two-phase Rankine system. Therefore, both the 50 percent loss in ΔT quoted by Hall for the OTEC Rankine heat exchangers and the heat exchanger costs are essentially eliminated for the Nitinol heat engine system. The first elimination will increase f directly, and the second will certainly modify the optimum ΔT allocation at a lower cost level.

Crouch's argument also applies to particular types of systems and therefore does not provide a fundamental limitation to thermocline energy conversion. For example, consider a system for which only the warm water from near the reservoir surface is included in the reservoir outflow, and the system heat sink is provided by cold water which flows from below the reservoir surface through the dam to the heat engine and is then returned through the dam to the reservoir. This system would result in an essentially infinite heat sink. (Parasitic pumping losses must be considered in cost optimization.) For this case, an analysis just analogous to that by Crouch results in a factor of 1/2 which multiplies the theoretical maximum power, instead of the 1/8 for the type of systems analyzed by Crouch.

Our purpose in (*1*) was to report the equivalent head available from solar-produced lake thermoclines, not to discuss factors that depend on the specific type of heat engine system selected for that application. The results of the OTEC Rankine studies should not be used as a basis for discarding a valuable energy resource. Rather, they should be utilized to focus attention on the development of non-Rankine heat engines and systems that are optimized for commercial utilization of the valuable thermocline thermal energy resource.

J. L. McNichols
W. S. Ginell
McDonnell Douglas Astronautics Company, Huntington Beach, California 92647
J. S. Cory
Cory Laboratories, Escondido, California 92025

References

1. J. L. McNichols, W. S. Ginell, J. S. Cory, *Science* **203**, 167 (1979).
2. TRW Systems Group, *Ocean Thermal Energy Conversion Research on an Engineering Evaluation and Test Program* (Publication PB-246 178, National Technical Information Service, Springfield, Va., 1975), vol. 3, p. I-2.

21 April 1980

Centennial

The 4 July issue will celebrate our 100th birthday. Part of the issue will portray the history of the magazine and its relationship to the American Association for the Advancement of Science. The major portion of the content will be devoted to an examination of the present status and progress of the sciences, applied sciences, and the interactions of science and technology with major societal problems.

Thermocline Temperature Differences and Realizable Energy

J.L MCNICHOLS, W.S GINELL and J.S CORY

Science **208** (4449), 1293.
DOI: 10.1126/science.208.4449.1293

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. The title *Science* is a registered trademark of AAAS.