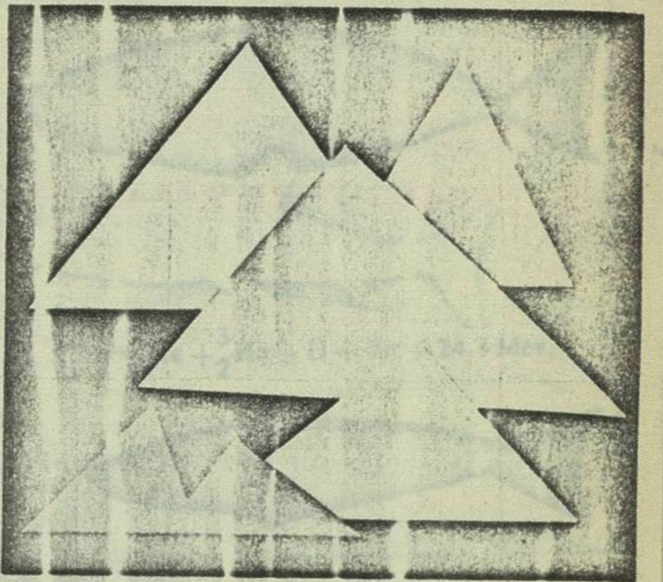
POWER IN THE YEAR 2001



Part 1—Dawn of the Solar Age

Those bounties of nature, our fossil fuels, will be effectively exhausted in 200 or so years. Before this comes to pass, we shall burn the seas and the rocks or, ultimately, directly tap the sun's heat for our energy needs. This is not a statement of desperation. Technologically, no insuperable problems exist. The core problem is rather one of bias and inertia that seems not to evaporate except under the heat of crisis. To place the energy picture of the not-too-distant future into focus, a series is initiated, in this issue, of major and innovative energy systems that have this in common. Any one of them, if fully exploited, could meet our energy needs for many millennia with minimal or no insult to the environment.

SAMUEL WALTERS[1]

"ENERGY," said James Clerk Maxwell, nineteenth-century British scientist, "is the go of things." And ever since Watt's engine in the eighteenth century used the chemical energy of wood and coal to power industrial machines, we have been "going" at an accelerated rate. Prior to this, for millennial times man plodded along, energy-wise, at a donkey walk. But between 1830 and 1860, we broke into a trot. Reaction and impulse turbines for extracting the potential energy of water stored at high heads were developed. On the heels of these developments came Otto, Daimler and Diesel. Their achievements, between 1874 and 1905, led to practical internal-combustion engines operating on liquid hydrocarbon fuels such as oil, gasoline and kerosene. At about the same time, Parsons developed the steam turbine and not long after that, at about the beginning of the twentieth century, the first steam-turbine-driven electric power generating plants went into operation. We broke into a canter.

Per capita energy consumption and population soared—together. Until recent times they have always moved together. In fact, curves of population and per capita energy consumption over the past score of millennia are indistinguishable from one another. They plot as a nearly horizontal line just above zero for the entire period of human history until the last thousand years or so. Then a barely perceptible rise begins as the present is approached. Here the curve turns abruptly upward in a nearly vertical rise toward the 1970 world population figure of about 3.6 billions. Curves of energy production from the fossil fuels behave similarly except that in the very recent past they begin at zero [1].[2]

We are probably now approaching full gallop. In terms of Q units of energy,[3] the energy transformation is startling. From the time of Christ until the middle of the last century mankind used about 8 Q. In the last century 4 Q were consumed, and, extrapolating from current trends, the need in the next century will be between 100 and 400 Q. (The United States alone, with only 6 percent of the world's population, consumes 37 percent of the world's energy.) Even if all known marginal and submarginal resources are considered, the problem of diversifying the energy source would not be alleviated. These resources are limited—about 81 Q for the United States and 452 Q for the entire planet [2].

Since the known recoverable reserves of fossil fuels are limited (6 Q for the United States and 23 Q for the entire world) and the supply of uranium 235 will be in short supply within 20 years, the human population

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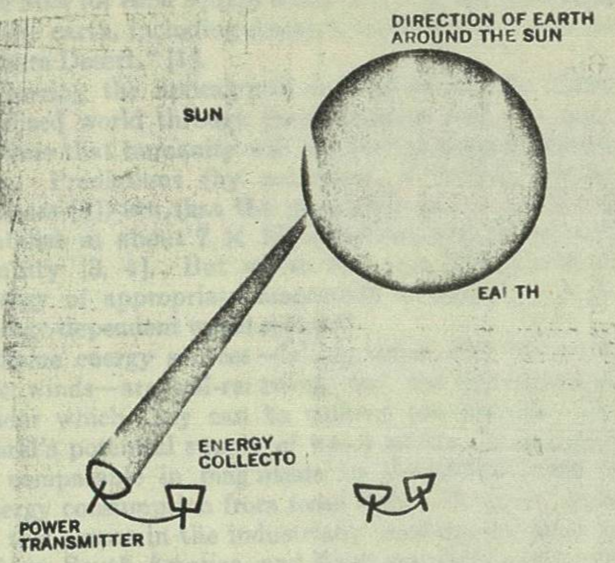
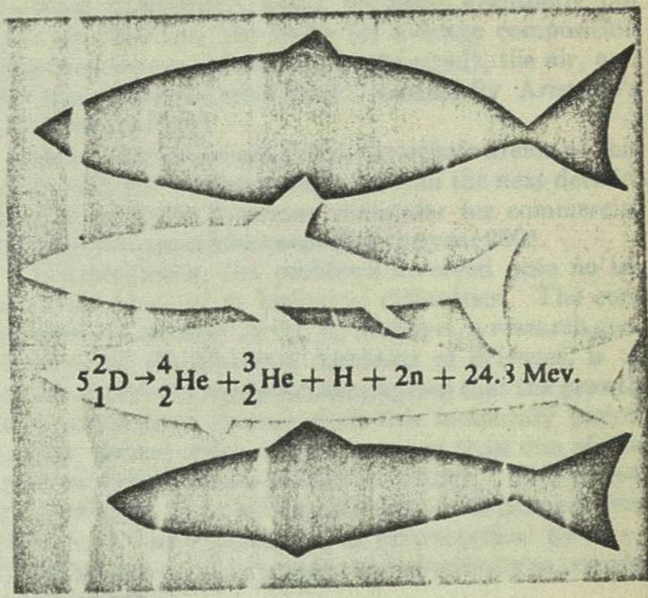
[2] Numbers in brackets designate References at end of article.

[3] 1 Q = 10^{18} Btu or 2.93×10^{14} kwh. Recall that the British thermal unit, or Btu, is defined as the heat necessary to raise by 1 deg F the temperature of 1 lb of water. To give a physical idea of the size of the Q it represents the heat liberated by the combustion of 38 billion tons of bituminous coal. Another example: If we had 400 million automobiles, each with a 100-hp engine, and ran them at full throttle night and day for an entire year, we would consume an amount of gasoline equivalent to about one Q of energy.





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urve must follow one of three possible courses [1]:

A continued rise for a brief period followed by a radual leveling to some stable figure which the world's nergy and material resources are capable of supporting for a long period of time.

- An overshoot of any possible stable level and a drop downward to eventually stabilize at some level compatible with the world's resources.
- Resource exhaustion and a general cultural decline. The curve would then reflect a population corresponding to the lowest energy consumption level of a primitive existence.

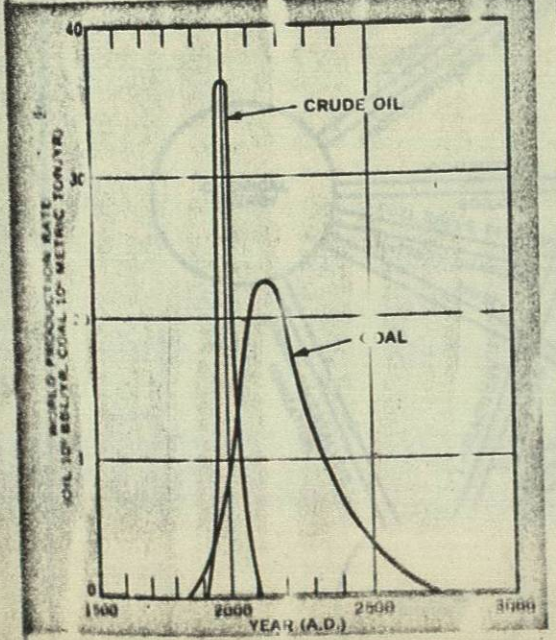
What is not possible is an unlimited population growth. Consider this: If the human doubling time of about 100 years were to persist, then in the year 2970 there would be about 10^{12} persons on earth. In fact, if the present world population were to double

TABLE
Reserves in Fossil Fuels

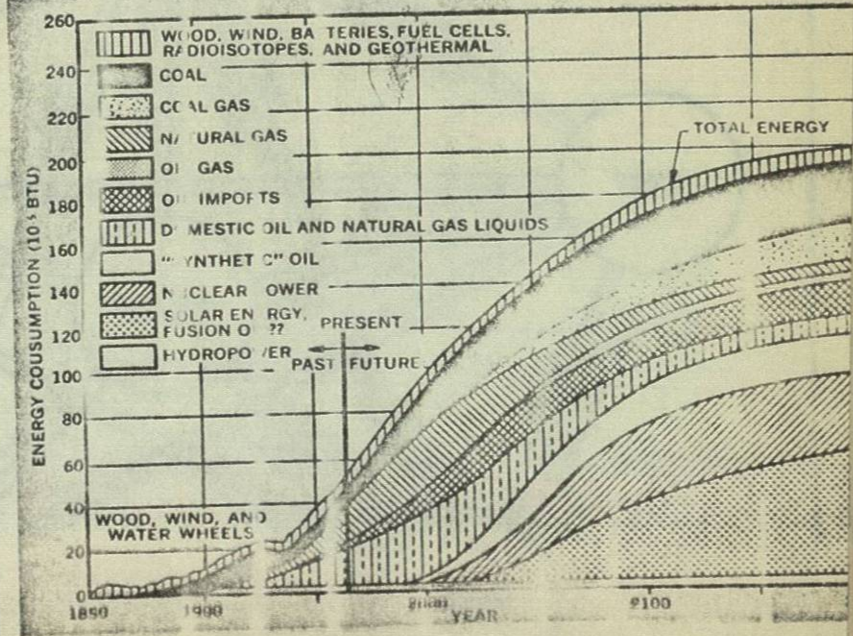
Fuel	U.S., Q	World, Q
Coal	4.600	18.00
Natural gas	0.310	2.11
Petroleum	0.278	1.70
Oil	0.298	1.70
Total	5.486	22.91

(From Duncan and McKelvey, U.S. Geological Survey, 1964 [5]).

World fossil fuel utilization rate. (From Ralph [6]).



Energy consumption in the United States, past, present, and future. (From Gaucher [7]).



but 15 or more times, "there would be in the year 2500, one man for each square meter on all of the land areas of the earth, including Antarctica, Greenland, and the Sahara Desert." [1].

Barring the apocalyptic destruction of the industrialized world through thermonuclear war, one must assume that humanity will opt for the second alternative. Predictions (by consensus of leading demographers [3]) are that the population of the earth will stabilize at about 7 × 10^9 sometime within the next century [3, 4]. But where then are the sources of energy of appropriate magnitude to sustain a high-energy-dependent world culture?

Some energy sources—falling water, the tides, and the winds—are self-renewing, but the circumstances under which they can be utilized are limited. The world's potential supply of water power, for example, is comparable in magnitude to the present rate of energy consumption from fossil fuels. However, most of this occurs in the industrially undeveloped areas of Africa, South America, and Southeast Asia, and could only be utilized by a parallel industrialization of these areas. In addition, although water power is capable of continuing for periods of geologic time, a practical limit in the case of large dams and reservoirs is set by the period of a few centuries required for the reservoirs to fill with sediments.

Geothermal and tidal energy are now being exploited in a few suitable sites around the world, but the ultimate amount of power from these sources does not promise to be larger than a small fraction of the world's present requirements. This leaves us with: nuclear energy, rock burning (fission) and sea burning (fusion); solar radiation; and the thermal heat of the oceans. As Alvin Weinberg, director of the AEC's Oak Ridge National Laboratory, notes, we must eventually fall back on "the sea, the rocks (of average composition since true ores will have been exhausted), the air, and the sun (equated with fire)...essentially Aristotle's four elements" [4].

Sea burning, although still a physicist's dream at this stage, may yet become a reality within the next decade. If so it could be a serious contender for commercial power in the quantities needed by the year 2001.

Technologically, the problems involved pose no insuperable physical or biological difficulties. The core problem, to paraphrase M. K. Hubbert, a research geophysicist of the National Academy of Sciences, is to uproot the deeply ingrained assumption that the growth rates which have characterized this temporary period are the normal order of things rather than one of the most abnormal phases of human history. This period is, he believes, "a brief transitional episode between two very much longer periods, each characterized by rates of change so slow as to be regarded essentially as periods of nongrowth."

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Hubbert, M. K., *Resources and Man*, Chap. 8. "Energy Sources," W. H. Freeman, San Francisco, Calif., 1969, p. 8.

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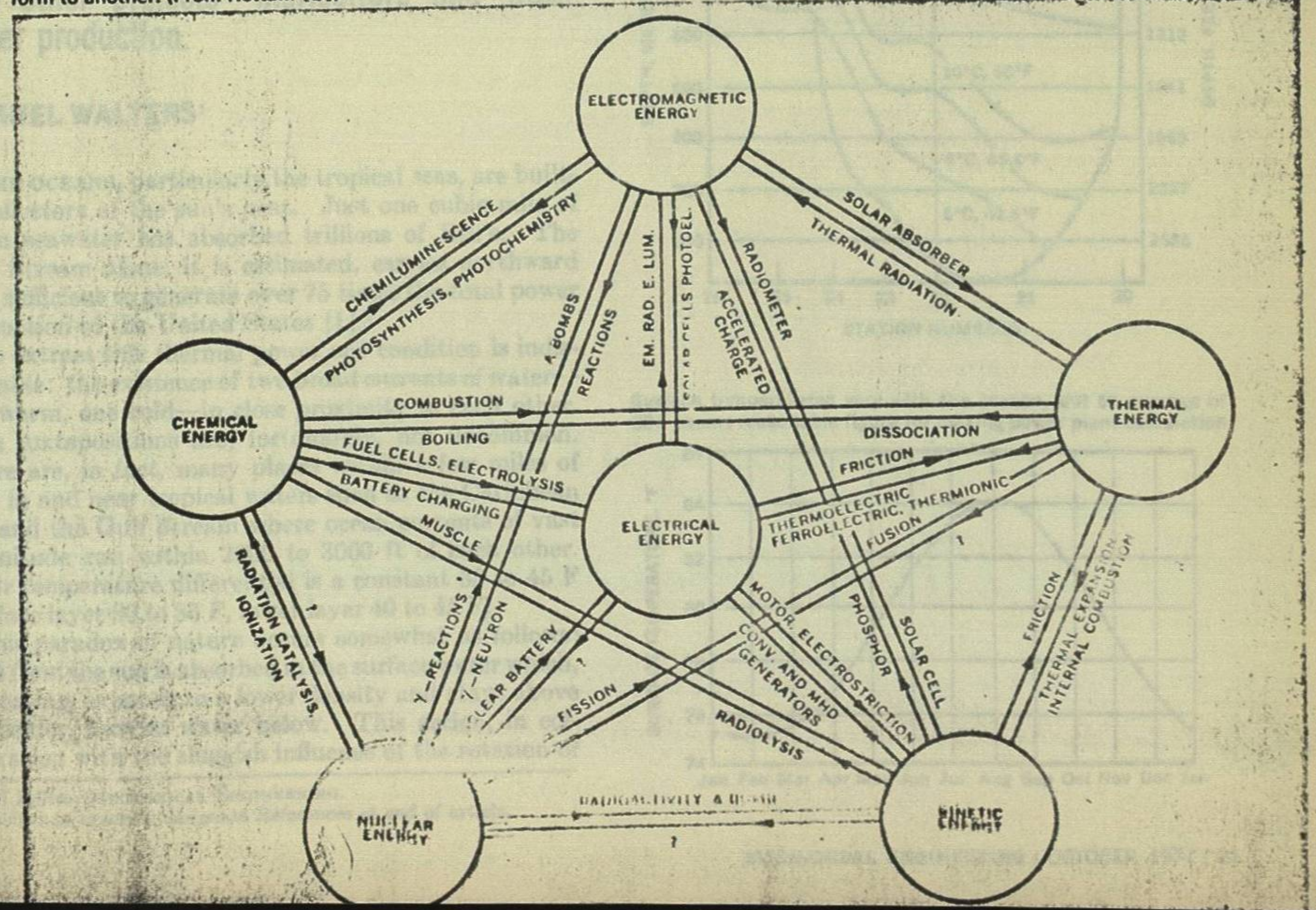
7 Gaucher, L., "Energy Sources of the Future of the United States," *J. Solar Energy Soc.*, Vol. 9, 1965.

Energy Conversion Chart. The circles represent the different forms of energy and the arrows the ways of converting energy from one form to another. (From Kettani [2]).



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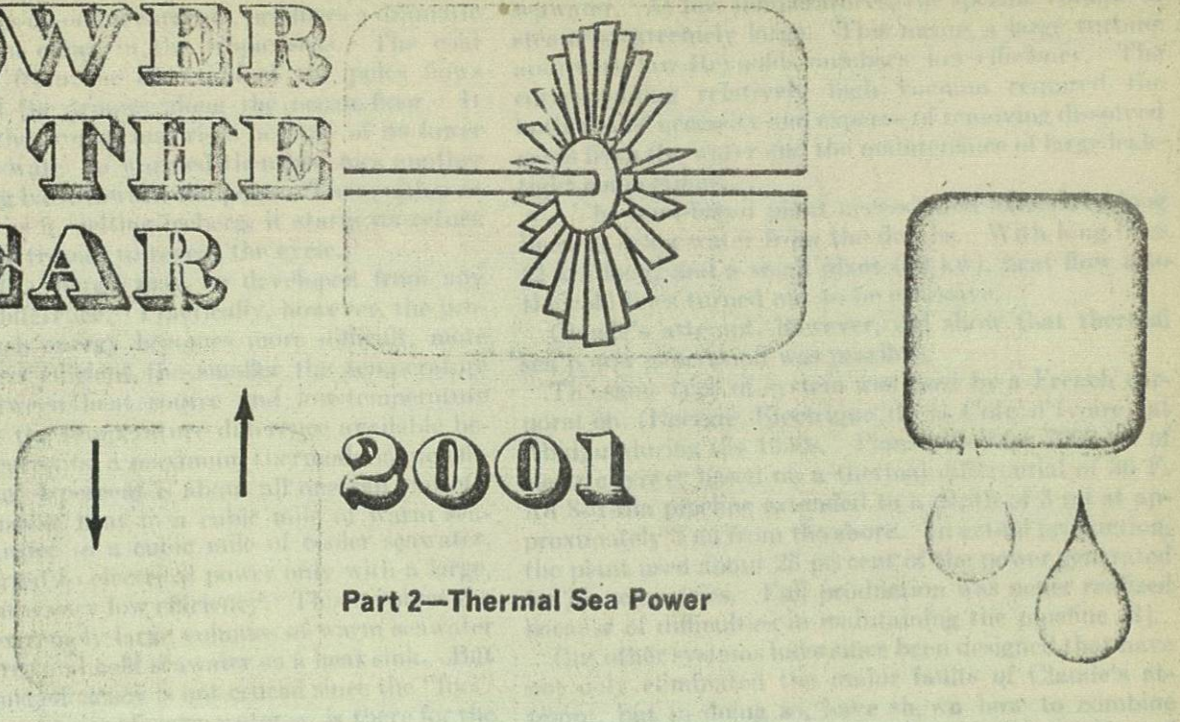

Part 2—Thermal Sea Power

Advances in underwater technology can now realize the old idea of generating power from temperature differences between tropical surface waters and colder currents flowing directly beneath. Such a tantalizing project is now underway in the Caribbean in combination with two other projects—mariculture and freshwater production.

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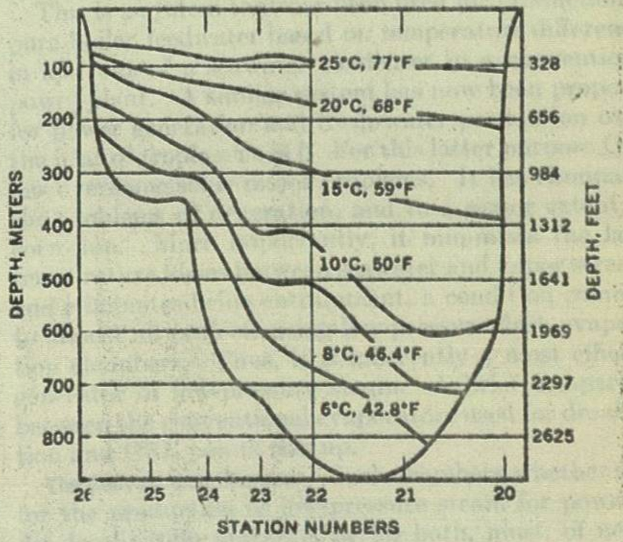
THE OCEANS, particularly the tropical seas, are built-in collectors of the sun's heat. Just one cubic mile of warm seawater has absorbed trillions of Btu's. The Gulf Stream alone, it is estimated, carries northward heat sufficient to generate over 75 times the total power production of the United States [1].[2]

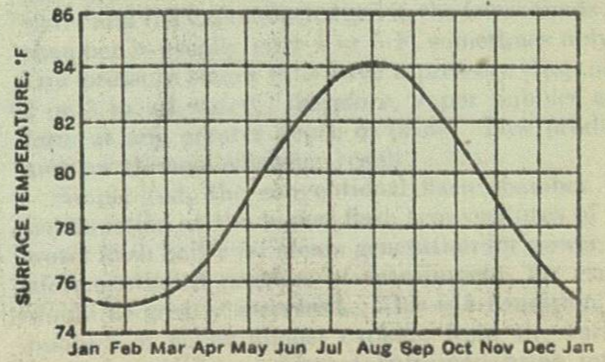
To extract this thermal power one condition is indispensable: the existence of two broad currents of water—one warm, one cold—in close proximity to each other. Such juxtapositions are, fortunately, not uncommon. There are, in fact, many places within a few miles of land in and near tropical waters such as the Caribbean Sea and the Gulf Stream where ocean currents of vast magnitude run within 2000 to 3000 ft of each other. Their temperature differential is a constant 35 to 45 F (surface layer 80 to 85 F, lower layer 40 to 45 F).

This paradox of nature occurs somewhat as follows: Heat from the sun is absorbed in the surface water which, on heating, expands to a lower density and stays above the colder, heavier water below. This action, in collaboration with the sluggish influence of the rotation of

Underwater temperatures in the straits of Florida, 30 miles from Miami. At 400 meters (1312 ft) the temperature is 43 F.



Surface temperatures vary with the season, but an average of 80 F seems reasonable figure for making power plant calculation



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