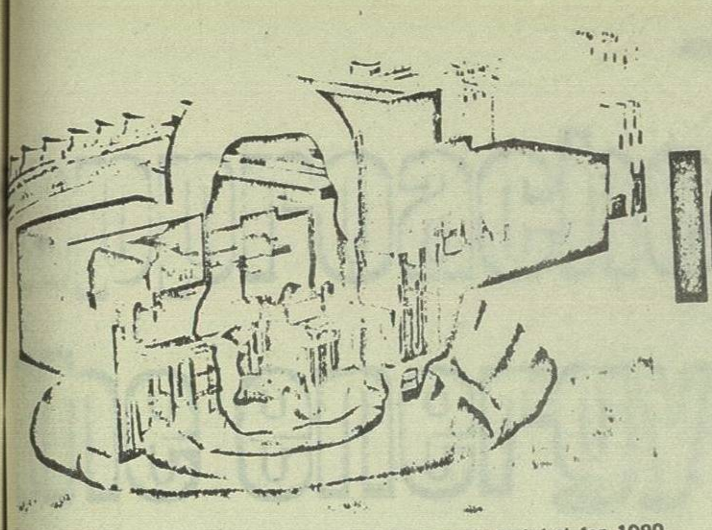

400 MW(e) LMFBR demonstration plant scheduled for 1980.

long-range resolving

Long-range possibilities for generation of prime energy (other than the nuclear breeder) are basically only three: solar, fusion, and geothermal. Predictions in favor of one or the other of these possibilities tend to take on the character of prophesy, principally because the prophet knows he will probably be dead by the time the returns are in. Fermi, for example, discussed the fast breeder, not expected before the mid-Eighties, in 1943. The prophets may be right, but a prudent overall energy policy must be based on the two firm alternatives—clean energy from coal and from nuclear sources, particularly from the breeder.

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Of the long-range possibilities—other than the breeder—for generation of prime energy, only three appear to represent a sufficiently large resource to make them potentially of great importance. These are solar, fusion, and geothermal.

Solar

H. C. Hottel and J. B. Howard in their book *New Energy Technology: Some Facts and Assessments*[2] state that until new knowledge is available, studies of large-scale power from the sun via the flat-plate collector are a waste of time and money. Yet in the last year there has been some revival of interest in solar power, largely as the result of some interesting proposals by Drs. Aden B. and Marjorie P. Meinel.[3] The Meinels' ideas are based on the use of films that absorb most of the incident solar radiation but reemit little infrared radiation. Thus in effect their collectors would be small greenhouses. In one concept proposed by the Meinels, tubes running east-west conduct molten sodium through the collection system. The tubes are enclosed in glass pipes that are evacuated to protect the selective radiation film on the tubes and to suppress heat transfer by convection and conduction. Fresnel lenses focus sunlight onto the tubes. Heat absorbed by the sodium is stored in a large vessel containing a eutectic mixture of salts with a suitable melting point. Heat is extracted from the storage units at 1000 F and used to generate steam, which drives turbogenerators at an efficiency of 41 percent. The Meinels estimate the capital outlay to be around $1000/kw.

We at the Oak Ridge National Laboratory, under a National Science Foundation contract, have briefly examined the idea of using the heat from sunlight to generate electricity. In general, our estimates of the situation are less optimistic than the estimates offered by proponents of the various systems. The storage system seems to present a particular difficulty: for a 1000-MWe plant, 16-hr storage of heat requires about 8×10^8 lb of salt that melts at a reasonable temperature. Moreover, the storage system would have to be even larger if allowance is made for prolonged periods of cloud cover, and heat storage appears completely impractical for smoothing out seasonal variations. Alternatives then might be batteries or generation of hydrogen for short-term storage, and hydrogen probably could even be used for seasonal storage.

We have tried to estimate the cost of such solar systems, but since nothing approaching a full design of a solar-energy power plant has been made, there is no way to obtain an accurate cost estimate for such a plant. However, it can be said that the cost of the converter plant—heat to electricity—will be completely dwarfed by the cost of the collector field and

[1] Director on leave; presently Visiting University Professor, Vanderbilt University.

[2] M.I.T. Press, Cambridge, Mass., 1971.

Based on a presentation at The Energy Crisis Forum held at the 1972 ASME Winter Annual Meeting.

[3] "Is It Time for a New Look at Solar Energy?" *Bulletin of the Atomic Scientists*, Vol. 27, No. 8, Oct. 1971, pp. 32-37.

approaches for the energy crisis

the storage plant, regardless of the type of storage used. We estimate about \$3000/kw for just the collector field of the first-of-a-kind plant. If we can rationalize and automate manufacture of modules (on-site production of glass, for example), this might be reduced to perhaps \$1100/kw. To this of course must be added the cost of the storage systems, heat-conversion equipment, etc. Thus a very rough estimate would put the cost of a solar plant at not less than \$1100/kw in 1972 dollars. This is \$800 more than for a fossil-fuel plant. At this price the solar plant would be competitive if the cost of fossil fuel rose to around \$1.87 per 10^6 Btu. Thus solar energy appears to be a poor economic bet compared with nuclear energy[6] (which is competitive with fossil fuel at, say, 30c/10 Btu). Should the breeder be unsuccessful (which seems very unlikely), ordinary water reactors would compete favorably with solar plants even if the price of uranium ore exceeded \$100/lb. At this price, the total cost of electricity from light-water reactors would be less than 2¢/kwh, compared to 2.3c/kwh from a solar plant that cost \$1100/kw.

Nevertheless, the U. S. should continue work on solar energy, if only to establish with better reliability both its cost and its technical feasibility. We could thereby determine an *upper* limit to the cost of prime energy in the very unlikely event that nuclear energy in the future encounters some unexpected and insurmountable obstacle.

Fusion

Two different approaches to fusion have developed: magnetic confinement and laser-induced microexplosions (so-called inertial confinement). In the case of magnetic confinement, the measure of success is the Lawson criterion: the product nt in a D-T plasma must exceed 10^{14} sec/cc and the ion temperature must be around 10 keV. The best that has been achieved in the various tokamaks is $n = 3 \times 10^{13}$, $t \sim 50 \times 10^{-3}$ sec, so that $nt \sim 10^{12}$. We thus need two additional orders of magnitude before the zeroth-order scientific feasibility can be established.

But even when a plasma with $nt > 10^{14}$ has been achieved, there are extremely serious technological problems that remain: the magnetic-field coils are superconducting, the lithium coolant is at ~1832 F, and the distance between these temperature regimes is only 6½ ft. Perhaps the knottiest question is the radiation damage to the inner vacuum wall: will it be necessary to replace the vacuum wall every couple of years because it swells or embrittles under the intensive bombardment of 14-MeV neutrons? And what about the non-negligible after-heat (10 MW in a 5000-MW reactor) and intense radioactivity induced in the walls, or the 100×10^6 curies of tritium in the reactor, or the necessity in D-T to breed tritium from lithium? These are not insoluble problems, but they are obviously tedious and tricky and it would be wrong to count on technical feasibility being demonstrated on any specific timetable.

The laser-induced microexplosions are a recent development about which little has been said publicly. Here small pellets of D-T ice are imploded by converging laser beams. The resulting microthermonuclear explosions are contained in a stout pressure vessel. One ingenious idea is to line the vessel with a swirling layer of liquid lithium that is filled with gas bubbles to increase its ability to absorb the microshocks.

Obviously there are difficulties: to get lasers with high enough power, to control the pellet dispenser, to absorb energy. For a practical power reactor, the laser energy that must be delivered in a fraction of a nanosecond exceeds 10^5 joules. The largest laser available today delivers 600 joules in 2 nanosec. But there is a fair enthusiasm for these methods, and it would be wrong to discount this possibility. By like token, this is a long-shot scheme that may or may not prove practical at some unspecified future date.

Geothermal

Here we are talking not about an inexhaustible energy source, but about one that is now in use and whose full potential has not yet been developed. As with the other systems, one can identify optimists and pessimists. Perhaps because of the impressive credentials of the most optimistic of the geothermal enthusiasts, Prof. Robert Rex of the University of