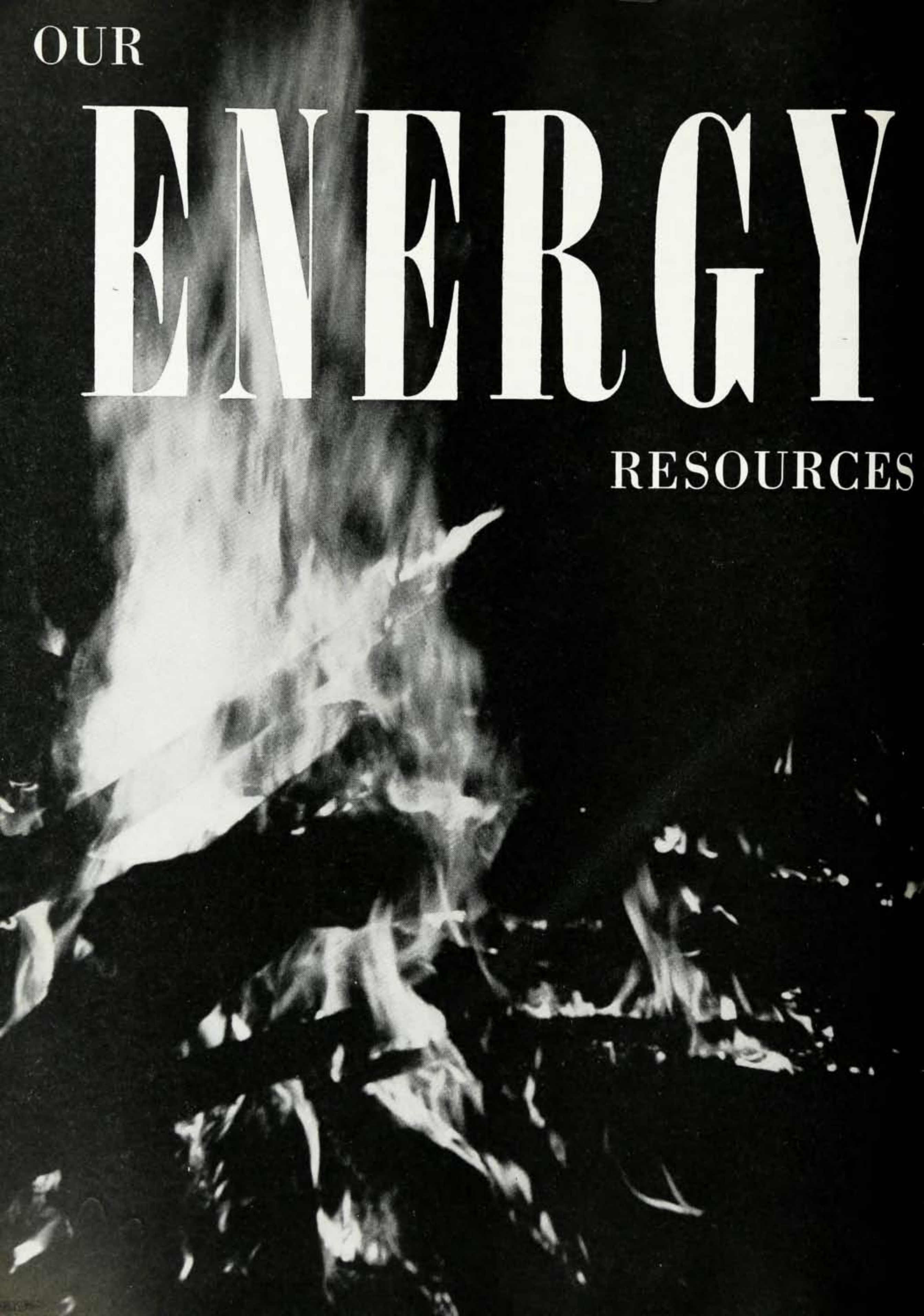
OUR ENERGY RESOURCES



Farrington Daniels • M. King Hubbert • Eugene P. Wigner

A chemist, a geophysicist, and a theoretical physicist discussed the rush with which we are using up our mineral and energy resources at a symposium held during the centennial meeting of the American Association for the Advancement of Science last fall. Here is their joint report on our spending spree and their thoughts on the possibilities of solar and nuclear energy as substitutes for the fossil fuels which are fast being used up.

Along with several other symposia of the Centennial Meeting of the American Association for the Advancement of Science, the symposium on the Sources of Energy was under the growing realization of the truths so aptly demonstrated by J. Osborne, W. Vogt, Stuart Chase and the conservationists: that humanity is on an unrepeatable spending spree, that we are using up mineral and energy resources on an unprecedented scale, and that these will run out in the foreseeable future. Because this symposium dealt with a rather well defined and clearly delimited facet of the whole problem, it could be attempted, with some prospect of success, to point to ways and means by which the apparently unescapable debacle can be avoided, at least as far as the exhaustion of energy sources is concerned. By making more direct use of the source of all terrestrial energy, the solar radiation, and by exploiting directly the source of solar radiation, the nuclear fuels, one can hope to provide the energy necessary for maintaining our standards of life into the indefinite future.

Fossil Fuels

The status of the energy resources which are in current use were reviewed by M. King Hubbert of the Shell Oil Company. His narrative started with the observation that since the year 1800 in the case of coal, and since its discovery in 1857 in the case of petroleum, the exploitation of energy from fossil fuels has shown a spectacular rise. During all of the nineteenth and a part of the present century, this rate of increase was such that the annual consumption of energy from these combined sources

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M. King Hubbert is Associate Director of Research of the Shell Oil Company's laboratory in Houston. Previously he has taught at Columbia University and was a member of the Bureau of Standards. He has worked in many branches of geology and is an authority in mineral economics and on the influence of mineral resources on industrial development.

Eugene P. Wigner is Professor of Mathematical Physics at Princeton University. His chief interest in academic life is the connection between group theory, quantum mechanics, and nuclear physics. During the war he was the leader of the group which prepared the overall design of the reactors which were built at Hanford.

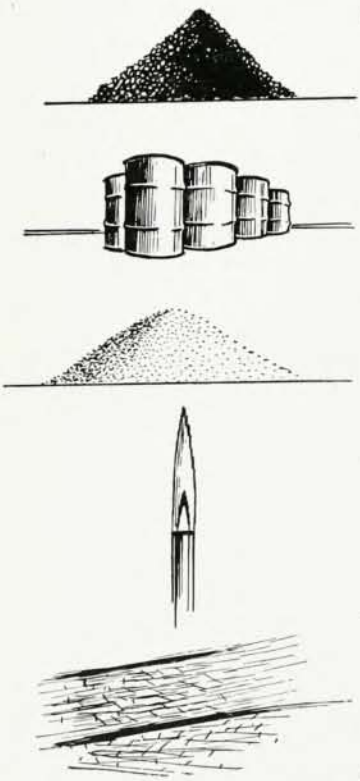
doubled approximately every seventeen years, and by the present time amounts to somewhat more than 15×10^{15} kilogram-calories per year.

To emphasize how recent is most of this development, it may be mentioned that the cumulative consumption of energy from fossil fuels in all human history amounts to about 700×10^{15} kilogram-calories, of which more than three-fourths have been consumed since the year 1900.

The rapid growth and large magnitude of the consumption of energy from fossil fuels, with the exploitation of metals and other mineral resources which this has made possible, has already been one of the most outstanding influences in the history of the world. In particular, the human population, which for thousands of years had been small and changing but slowly, began a rapid increase about the beginning of the sixteenth century, increasing from about four hundred million in 1500 to an estimated two and one-fifth billion at present. It is currently increasing at such a rate as to double approximately once per century, giving us the threat of serious overpopulation within the next few centuries.

In terms of human history the fossil fuels are essentially fixed resources which required some five hundred million years to accumulate. Furthermore, they are finite in quantity and the order of their magnitude is known. Consequently in their exploitation the quantity remaining is the difference between the amount initially present and that which has been consumed already. From these facts it follows that the rate of energy production from fossil fuels may rise and pass through one or a succession of maxima, but must ultimately decline to zero.

The energy contents of the fossil fuels initially present and the amount consumed already are approximately as follows:



FUEL	AMOUNT INITIALLY PRESENT (in kilogram-calories)	QUANTITY USED (in kilogram-calories)	PERCENT
COAL	46.0×10^{18}	0.59×10^{18}	1.3
PETROLEUM	1.5×10^{18}	0.087×10^{18}	5.7
TAR SANDS	0.3×10^{18}	—	—
NATURAL GAS	0.6×10^{18}	0.034×10^{18}	5.7
OIL SHALE	1.5×10^{18}	—	—
TOTAL FOSSIL FUELS	49.9×10^{18}	0.7×10^{18}	1.43

How long it may be before final decline sets in depends upon how much greater becomes the annual rate of consumption. Presumably this will continue to increase for some time. The more it does so, the sooner will exhaustion begin to be felt and it is not improbable that this will come about within the next century or two.

Thus, unless some new element enters the picture, we are faced with two possibilities: we may continue our unbridled expansion, as we have in the past, until crises result from overpopulation and exhaustion of non-replaceable resources, and thereafter decline almost as rapidly as we have risen; or we may manage to level off our population at some comfortable figure and make an orderly transition over to new sources of energy and inexhaustible low-grade material deposits—a state capable of being maintained more or less indefinitely.

Whether we shall make the former or the latter choice is one of the great problems confronting modern civilization, and appears to rest largely upon whether we can overcome the cultural lag between the comparatively simple physical, chemical and biological requirements of a high-energy social order, and our behavior based on an agrarian and prescientific past.

Solar Energy

Farrington Daniels and Eugene P. Wigner were concerned with the question whether the second alternative really exists, how it might be realized, and presented on the whole a rather hopeful picture. It takes the sun only a few weeks to bestow upon the earth, in the form of light, the amount of energy which is present in all the coal under ground. In other words, the accidental storage of the sun's radiation in the form of coal and oil was a most ineffective one: during all the hundreds of millions of years since the earth's birth, it put away only a few weeks' supply. No wonder that this will not last long. The situation would be entirely different if we could tap the sun's rays directly: even assuming a relatively poor efficiency we can hope to obtain more and for a longer period than if we rely on the accidentally stored supply. Even water power, which surely constitutes only a very small fraction of the sunrays' energy, could well provide us, if all of it could be utilized, with the amount of energy which we use currently.

The difficulty of using the sun's radiation directly originates from the great dilution in which the energy from the sun reaches us. In order to concentrate it by lenses and mirrors, we would have to cover a noticeable fraction of the earth's surface by optical instruments. Fortunately nature provided us with a better means: plants store up, in their substance, a few hundredths of one percent of the sun's annual radiation falling on them, and there is reason to believe that this figure could be increased somewhat by breeding more efficient plants and providing adequate water and fertilizer. On the basis of our improved understanding of photochemical reactions, Farrington Daniels estimated that under ideal conditions the *theoretical* limit for the efficiency of conversion of solar radiation energy into chemical energy of plants growing one third of a year might be as high as three percent of the year's radiation. Once the radiative energy is transformed into chemical energy, forming the body of a plant, it is sufficiently concentrated even for industrial uses. It is, of course, most unlikely that the theoretical limit of three percent can actually be ever realized in practice. Its realization would demand a high carbon dioxide concentration in the atmosphere and low light intensity—conditions

which are in a sense contradictory to the program of utilization of solar energy on a large scale. However, even if the ultimate figure will have to fall far short of the theoretical three percent, there remains the challenging goal of raising the presently obtainable efficiency of a hundredth of a percent quite considerably.

Admittedly these are dreams, but reassuring dreams in view of the precarious amount of the resources of fossil fuels.

Nuclear Energy

The prospects of substituting nuclear energy for fossil fuels was discussed by Dr. Wigner. We envisage at present the use of only two nuclear fuels: uranium and thorium. Some uranium and thorium is present in the earth's crust in a high concentration, in rich ores, but the energy represented by these is probably smaller than that of fossil fuels. However, there is an inexhaustible supply of nuclear energy in ores, sands, and rocks in which the thorium and uranium are greatly diluted by inert material. The first problem is to extract and to concentrate these. The tremendous amount of nuclear energy of our rocks can perhaps be best illustrated by the observation that the theoretical energy of the uranium contained in an *average* ton of rocks is greater than the energy content of a ton of pure coal.

However, we have not yet converted even the energy of the purest uranium metal into useful power. There are not only, and perhaps not even mainly, technical difficulties in our way. The administrative and human problems are equally great, and the fact is that, *for the time being*, we are well provided with fossil fuels. The time surely will come when mankind will need new sources of energy, but that time is not yet here. For this reason, the first really useful applications of nuclear energy are likely to be specialized ones and such in which it does not have to contend with the competition of coal and oil. The most important application to date, the procurement of research tools for many branches of science, in the form of radio tracers, is of this nature.

The property of nuclear fuels, which is likely to help them most in establishing themselves as sources of energy even while the fossil fuels last, is their enormous concentration. Pure uranium contains, weight for weight, about three million times more energy than coal. This makes it the ideal fuel for long-range transportation and it is not unreasonable to speculate even about its use, and about the difficulties of its use, for extraterrestrial travel.

Once the fossil fuels have run out, nuclear energy will have to compete with sunshine. The higher concentration of the former and the omnipresence of the latter suggest that the former may find its application mainly where large amounts of energy are needed, the latter in smaller plants. In both cases, it will require much ingenious thinking and perhaps even more hard and persevering work before the dreams of today can become the reality of tomorrow.

The application of sunshine to small installations was dramatically illustrated by the last speaker, Maria Telkes. Her house, near Boston, just completed, has no conventional heating system and no fuel is used to keep it warm. It has, on its roof, a large dark metal plate, about equal in area to that of the house, which absorbs the sun's radiation falling upon it. The heat is transferred from this metal plate by air to a heat collector from which it is withdrawn as needed to keep the temperature of the house comfortable. Here indeed is the valiant beginning, if only a first beginning, to make ourselves independent of fossil fuels.

Maria Telkes' sun-heated house at Dover, Massachusetts, uses the heat of fusion of inexpensive chemical compounds to store solar energy. The storage capacity is sufficient to bank a heat supply for ten average winter days in that climate.

George H. Davis Studio Photo.