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Presidential Address

ENERGY AND THE FUTURE OF MANKIND

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Of all the abstract concepts of science, there is none which can compare in importance with the concept of energy. There is little need for me to explain to this Society the significance of the term energy, but I should perhaps remind you of the well-known forms which energy takes, viz., the forms of light, heat, sound, electricity, and the even more familiar mechanical forms of kinetic energy (the energy of motion—exemplified by a moving bullet), and potential energy (the energy of position—exemplified by a wound clock spring). Then, too, energy can assume a chemical form, such as the energy contained in fuel ; and, finally, we have of recent years received startling evidence of the existence of atomic energy.

The various things that happen on the earth, all actions, whether of man, animals or of plants, all involve a conversion of energy from one form to another. The explosion of an atomic bomb, the eruption of a volcano, a lightning flash, all represent well-understood types of energy conversion. At the other end of the scale, the ticking of a watch, the uttering of a word, vision, hearing, even the reception of a sensation and the thinking of a thought, all imply energy conversions.

In all these conversions, there is no new energy created and no energy destroyed. The energy which was in the universe at the beginning is still in existence and no new energy has appeared. New forms appear and old forms disappear, but the gain always balances the loss. This law is undoubtedly the most important law of science. It is really this law which gives significance to the idea of energy ; without it the concept would be meaningless.

This law refers to the total energy in the universe, not the energy actually contained in or on the earth. The earth's energy is not necessarily constant in quantity ; in fact it is almost certainly varying all the time. Energy is being added to the earth by the light and other radiations received from the sun (and to a less extent from other celestial objects), and energy is being lost by invisible radiations and in other ways. The gain and the loss nearly balance out, but usually there is not an exact balance.

The standard of living of the human race, even its survival depends on the energy possessed by the earth. But the possession of energy alone is not sufficient. The energy must also be in a form capable of conversion to other forms, that is the energy must be *available.* Without such available energy nothing can be made to happen, not even the minor actions necessary for living. Unfortunately, energy can easily—too easily, in fact—become converted into a form where it is no longer available. Energy in the form of heat, *i.e.*, the energy associated with temperature, is never completely available. Only that part of the heat of any material object which corresponds to a difference in temperature between it and its surroundings can in practice be converted into other forms of energy. The hot gases in a motor car cylinder have available energy ; when they are cooled to the temperature of the cylinder they have none.

Unfortunately, energy has a tendency to become converted into heat. All energy conversions carried out on the earth, with or without our direction, result in a certain proportion of the energy going into the form of heat. There is, so to speak, a heat tax on all conversions. While at first this heat energy may be still partly in available form, the processes of conduction, etc., soon equalize the temperatures and render the energy unavailable and therefore virtually useless. One might think that there would be a possibility of obtaining energy on account of the temperature difference between the surface of the earth and the cold empty space within the shadow of the earth. Actually, this temperature difference does allow the heat energy of the earth and air one important energy conversion, the conversion into infra-red radiation. This conversion is the ultimate fate of the heat energy. As a result of it there is a continuous emission of radiation into empty space ; this is the main way in which the earth loses energy. We can scarcely contemplate making use of the temperature difference to obtain other forms of energy, since, apart from the difficulties involved, to do so would lower the average air temperature and human life can only be maintained over a certain very limited range of temperature.

We have then on the earth two sorts of energy, useful energy, that is, energy available for the operation of our machines, available for making things happen, and useless energy, that is, unavailable energy. When useful energy becomes converted into useless energy we can speak of it as becoming *degraded* or *consumed*, as it is no longer available.

The most important of the machines is, of course, man himself. I have already mentioned that the slightest action of the body, breathing, the beating of the heart, even the transference of sensation, all represent energy conversions. A high heat-tax is imposed on all these conversions, so that the processes of life inevitably result in the consumption of energy. To maintain life, therefore, an intake of energy is necessary. This intake is in the form of chemical energy associated with the food we eat.

The amount of energy intake depends on the sort of life a man is leading, but a representative value for the average rate is about 150 watts ; this means 3.5 kilowatt-hours each day. (These units are the most familiar of the energy units ; a kilowatt-hour is the unit ordinarily used in selling electrical energy—150 watts is about a fifth of a horse-power.)

As a result of the generation of heat within the human body, particularly within the trunk, the temperature of the interior of the body is, under most climatic conditions, higher than that of its surroundings. This interior temperature is subject to a system of automatic controls. These regulate the way in which the body loses heat, and thus maintain the interior temperature closely constant. For example, if the temperature of the surroundings increases somewhat, certain mechanisms increase the ease with which heat passes from the interior of the skin ; if the surroundings become colder, they decrease it. (Other mechanisms also are involved, but details do not concern us.)

Man is assisted in this adjustment of his temperature by the fact that the average air-temperature at sea-level is not very far removed from the temperature at which the human body functions. This air-temperature depends on the amount of radiation received from the sun. As the average temperature of the earth increases, the rate at which it loses energy to empty space also increases, and since loss and gain must roughly balance, the greater the amount of energy the sun provides, the higher the temperature of the earth.

The actual air-temperature at any place may vary quite considerably. Over a certain range of conditions man's regulating mechanism can cope with the situation, but towards the limits of this range the adjustment involves considerable strain and discomfort. At the lower end of the temperature range the wearing of clothing and the use of houses assist materially in this adjustment. They even permit life under conditions in which otherwise it would be possible only by undertaking continuous strenuous muscular exercise; such exertion, of course, increases the heat evolution within the body.

In his quest for comfort man has resorted to other measures, more important from the point of view of my discussion to-night. He can produce in a limited region such as the room of a house, a modified climate, hotter or colder than the external climate, as may be required. This modification of climate always demands the consumption of energy, *i.e.*, the conversion of energy from a useful form into a form of heat which is useless. The actual steps in this degradation will differ in different cases, but it always occurs. The amount of energy consumed depends not only on the temperature differences maintained, but also on such things as heat insulation, etc. Considerable technical development has been devoted to reducing this wastage of energy. Even now, however, a man may consume more energy keeping warm on a winter evening than he consumes as food during the day.

If man's needs were limited to food and warmth his energy requirements would be relatively easily met. But modern man demands far more. He requires to cook his food to render it more palatable ; in so doing he may expend almost as much energy as the food itself represents. The growing of his food is no longer a matter which occupies merely his own muscular effort. He requires all sorts of implements, many of them requiring additional sources of energy, particularly fuel, for their operation.

To obtain these and other implements man occupies himself in manufacturing, making not only implements, but also houses and the attributes of comfort, and making amusements and luxuries. All manufacturing involves the consumption of energy. Energy is consumed at the mine where the ore is obtained, energy is consumed at the smelters where the metal is extracted, energy is consumed on the railways when the metal is taken to the factory, and energy is consumed at the factory itself and in the subsequent journey to the user. Mostly such energy is the result of the burning of fuel, coming from the chemical energy of wood and coal and oil. But energy must also be provided to the men who work in these occupations, energy to provide them with the necessary food and warmth and the other requirements of modern civilization.

There is a link between the cost in money of a manufactured article and the amount of energy consumed in making it. They do not correspond exactly, for often there are other factors involved, but it is possible to estimate roughly the comparative cost of articles if we know the energy involved in making them. Of course we have to make the machinery used in making the articles, and we must include part of the energy-cost of the machinery when we estimate the energy-cost of its product.

Among the most important products of man's labour are the fuels themselves ; coal and coal products, petroleum and its products, forest products, etc. The relative energy-profit on such operations is a matter of the greatest concern to any community. To find the relative energy profit, we add together the fuel energy expended in mining, transport, refining, etc., and the food, etc., expressed in terms of energy, required by the personnel employed. Then we subtract the result from the energy provided by the fuel. This gives the profit, and we can express it as a percentage in the usual way. If the total cost per ton is, say, 3,000 kw.-hrs., and if the energy we obtained from a ton is, say, 10,000 kw.-hrs., the relative energy profit is 230 per cent. It is not a coincidence that the United States, which has plenty of easily-won fuel, is the richest country in the world. On the other hand, England's post-war financial difficulties are related to the increasing difficulty of winning coal in a country whose best coal-seams have already been exhausted.

The manufacturing activities of a modern industrialized country may consume energy at the rate of more than 1,000 watts per head of population, compared with the 150 watts per head required as food. This does not, of course, represent the whole requirements of the population ; it requires energy for artificial lighting, for transport, for radio and other entertainment. As the use of motor cars becomes more widespread, as the devices for providing entertainment become more elaborate, the demands on energy increase. A petrol consumption of 100 gallons per annum, a quite modest figure in pre-rationing days, represents an average energy consumption at the rate of around 500 watts.

Average energy consumption rates for a typical person are somewhat as follows :—

Food	150 watts
Warmth	200 ,,
Manufacturing	2000 ,,
Transport	200 ,,
Miscellaneous	450 ,,
TOTAL	3000 ,,

TOTAL DAILY CONSUMPTION—72 KW-hrs.

My estimates are based on peace-time requirements. In time of war, energy is consumed at a rate many times greater than in peace, and with the introduction of new weapons the consumption rises hugely. The dropping of a single atomic bomb each day alone corresponds to a consumption at the rate of forty thousand million watts, about 20 watts per head of the world's population.

If the spirit of man throughout the world is to be freed from the chains of poverty, drudgery, and discomfort, if the standards of luxury enjoyed among communities such as ours are to be shared by all mankind, the average consumption of energy, food and fuel must inevitably increase, and increase by a considerable factor. If war, disease and famine decrease their toll, as we hope will be the case, the number of energy consumers will also increase ; again we will require more energy. How then are we to maintain and increase our present supplies of available energy ?

Let us first examine the sources from which we obtain the energy we consume at the present day. The most important group of these sources, and the only absolutely indispensable one, is the food supplies. We eat many things, some animal, some vegetable. Since the animals, however, depend on vegetation as their source of food, we can regard vegetation as the ultimate source of all our food. We must remember. of course, that the energy we obtain from eating the flesh of animals is but a very small fraction of the energy those animals have consumed.

The growth of plants represents, in general, a storage of energy, This energy is obtained from the light which the plant receives from the sun by a photosynthetic process. This most important process occurs chiefly, if not entirely, in the green leaves of the plant. To be precise, it occurs in the *chloroplasts*, organs which contain the pigment *chlorophyll* together with other pigments which may or may not participate in the process. Under the influence of the light absorbed in the chloroplasts, carbon dioxide is synthesized into sugar and energy is thereby stored as chemical energy. This is the principal photosynthetic process, but others also occur with which I shall not deal in detail. The overall efficiency of the process is unfortunately very low. It has been estimated that, of the solar energy falling on a green leaf, only two-thirds of one per cent. is actually stored as chemical energy.

PRODUCTION OF USEFUL ENERGY.

Mechanism	Uses that part of the Sun's Energy which falls on	Efficiency of use
Plants (photosynthesis in chloroplasts containing chlorophyll)	Green leaves and green vegetation generally	0.66%
Hydro-electricity (rain on mountains)	Ocean and other water ...	0.001% (?)
Winds (heating of tropical regions) ...	All earth	perhaps 0.00001%
Photo-voltaic effect	Photo-voltaic cells	0.3%

The efficiency is not the same for all parts of the light spectrum, though this seems to depend to some extent on the species of plant involved. The energy of the infra-red radiation, which makes up about half of the energy in sunlight, is not stored at all by plants.

Plants are of many kinds, not all of which contribute to our food supplies either directly or indirectly. Among the non-food-producing plants, however, are many which can still be regarded as useful ; for constructional timber, for example, or for fuel. The fuels we are using at the present day, chiefly wood, coal and oil, were all derived from vegetation which, in the past, grew with the aid of sunlight. Coal and oil have suffered many chemical changes but have still preserved the chemical energy given to them by the sunlight. Oil may, in fact, have acquired additional energy, derived perhaps from the residuum of the large heat energy which the earth possessed before it became a cold star.

In spite of the low efficiency of the photosynthetic process, it is of vital importance, since it represents virtually the only one which is replenishing those stocks of available energy which we are at present using in such a prodigal fashion. Needless to say, the rate of exploitation far outreaches the rate of restoration ; I doubt if there is any country in the world which is actually increasing its reserves of energy in the form of food and fuel.

These considerations bring home to us the seriousness of the tragedy involved in the loss of arable land owing to wasteful farming transforming it into a desert or dust-bowl. This has been stressed in relation to the growing shortage of food—of which Sir John Boyd-Orr rightly warned the peoples of the world—but this food shortage is but one aspect of the more serious problem. Possibly, by using some of the areas at present devoted to forests for food production, the food position could be corrected, at least for some years, but this would aggravate the general energy shortage. On the other hand, if ample supplies of disposable energy become available, if the general energy problem is solved, there would probably be no need for anxiety regarding the food position, for I have little doubt that organic chemists will be able to discover efficient processes (perhaps some new photosynthetic processes) whereby foodstuffs can be made from carbon dioxide in factories in much the same way as they are now made naturally in plants.

Incidentally, calculations which have been made of the extent of coal and oil reserves in various countries may be misleading, for upon the completion of exploitation of the richer and more accessible deposits the energy costs of mining and transport will rise, perhaps sharply. Without a serious drop in the standard of living, exploitation of the remaining deposits may thus be impracticable. It is well known that for technical and economic reasons, few coal-seams are ever completely removed, and the cost of removing the residues at a later date may well be prohibitive.

Fortunately, we do not depend entirely on fuel for the energy we require for domestic heating, manufacturing and transport. A second process initiated by the solar radiation provides us with a second source, that of hydro-electric energy. The primary effect of the solar radiation in this case is the evaporation of water, principally from the surface of the oceans, but also from moist land, lakes, etc. The air thus moistened may be carried by the winds, which are themselves a product of solar radiation, over mountains and highlands and there, by cooling, the moisture is deposited as rain. The water collecting at the high altitude possesses energy, potential energy, and by suitably directing the water-stream as it flows towards the sea, we can convert some of this potential energy into other useful forms. In modern times, electricity is usually the form of energy produced.

This energy is not produced without cost, *i.e.*, without an initial energy-outlay. Energy must be used in constructing dams, canals, pipes, turbines, dynamos, etc. Most of the hydro-electric schemes which have been installed in different parts of the world, however, have proved highly profitable undertakings. The energy-cost of construction has been covered by the energy produced within a relatively small number of years. Probably there are still many possibilities for highly profitable installations of hydro-electric schemes throughout the world, and many others which, with care, would eventually return a profit in energy, but only after many years.

Unfortunately there are conflicting demands on the available streams of water in many countries, particularly in Australia. We have frequently to choose between the utilization of the water for stimulating an increase in food-production, thereby employing usefully more of the sun's radiation, or obtaining electric power from it directly. Sometimes it is very difficult to determine which of these alternatives will give the greatest overall energy-profit.

I have tried to obtain an estimate, for comparison with the plant-growth method of utilizing solar radiation, of the average overall efficiency of the production of electric power by evaporation from the oceans. I can find no published figures, but on very rough assumptions, I arrive at a figure of one part in 100,000 of the energy falling upon the ocean being potentially convertible into hydro-electric energy. This is probably a considerable over-estimate. Continental Australia with its low rainfall, and small areas of high lands, is rather worse off than most countries in relation to its size, as far as possibilities of hydro-electric generation is concerned.

Other means of utilizing solar energy have also been used to a limited extent. Perhaps the most important of these is the use of wind-power which was developed at one stage in the earth's history to a considerable degree, but recently tending to be abandoned on account of its unreliability. It is extremely difficult, in fact impossible, to estimate the overall efficiency of the wind-power method of using solar energy, but it must be extremely low.

An interesting method for converting solar radiation into available energy which has been suggested is the application of the *photo-voltaic effect*. In the photo-voltaic cell, a comparatively simple electrical device, electrical energy is generated when energy in the form of light falls on the cell. Photo-voltaic cells are in fairly general use as illumination-meters, photographic exposure-meters, and so on. It has been estimated that the overall efficiency of the ordinary selenium photo-voltaic cell is about one-third of one per cent. This method of utilizing energy would thus be only about half as efficient as the utilization by plants. It would have the advantage, however, that a supply of water, salts, etc., would not be needed, so it might be quite convenient for use in desert and semi-desert areas, such as exist in parts of this country. It has been estimated that 4,000 watts of power could be obtained from an acre covered with such cells. Unfortunately, the cost in energy of the manufacture of the cells is so high that it would be quite uneconomic to proceed with large-scale projects on this basis.

Claims have been made by certain Russian investigators that a much more efficient form of photo-voltaic cell has been discovered. If these claims are substantiated, the invention may prove a very valuable one, especially to countries like Australia. Maybe in the future, when ruthless agriculture has denuded our mountains of all but solid rock and converted our plains into deserts, the countryside will be covered with photo-voltaic cells instead of forests, and maintenance engineers will take the place of tillers of the soil.

It should not be thought, of course, that the methods already known for utilizing the sun's energy are necessarily the only or even the best methods available. The total average rate at which energy is received from the sun works out at about two hundred million watts per head of population. Compared with this figure our most extravagant requirements appear trivial. Our difficulties arise only from the extraordinary inefficiency of all our methods of using sunlight. The situation is actually somewhat worse than would appear from what I have said, for only a small fraction of the sunlight actually falls upon green vegetation ; only a part of the potential hydro-electric power can actually be obtained because of cost of installation, and so on.

It is perhaps surprising that so few deliberate searches are being carried out for new methods of converting solar radiation into commercially useful energy. The reason is the absence of any obvious lead, save the photo-voltaic cell scheme I have already mentioned. Other possible schemes, such as the use of the thermo-electric effect, for example, have been shown to be completely unprofitable. In the circumstances, the solution of the problem is more likely to arise out of discoveries in a completely unrelated field of physical or biophysical research than from the results of investigations designed specially to this end.

At the present time, the problem of the world's energy deficiency is being tackled along rather different lines. To understand this work, we must enquire into the actual source of the solar radiation ; we must determine why the sun retains its temperature, in spite of the enormous amount of energy it is continually pouring out, mainly into the unbounded vastness of interstellar space. The rate at which the sun loses energy is nearly four hundred quadrillion watts (4×10^{26} watts), and some process of energy-conversion must necessarily be occurring within the sun for such an emission to continue without decreasing temperature.

It now seems fairly certain that the sun derives its high temperature from the continuous conversion of its *atomic energy* into heat. The existence of atomic energy has been recognized for a comparatively few years. Its nature can be approximately explained in the following way :

Atoms are the building-blocks out of which matter is built, but an atom itself is built up of smaller bits, rather in the way that the solar system is built. Most of these sub-atomic particles are unimportant for our present purpose, but there is in each atom one *nucleus* which is, so to speak, the real body of the atom. This nucleus possesses most of the mass of the atom, and with the nucleus is associated a certain amount of energy. This energy is termed atomic energy. Atomic energy is then really *nuclear* energy. It is conceivable that a nucleus might go out of existence, in some sort of catastrophic process, in which case the atomic energy would be converted into another form, probably into radiation. Naturally, the mass would disappear with the disappearance of the nucleus. On modern views, mass is really a measure of total energy and, if a nucleus or anything else loses energy, it loses mass in proportion.

Such catastrophic disappearance of a nucleus has never been detected. We do know of cases, however, in which part of the nuclear energy becomes converted into other forms, and consequently the mass, the energy indicator, becomes reduced. For example, it can happen when a nucleus splits up into two separate nuclei ; the atomic energies associated with two separate nuclei, added together, being in certain cases less than the atomic energy associated with the single nucleus. This disintegration process can occur spontaneously in *radioactive* elements such as radium ; in fact, the value of radium as a method of treating diseases is closely bound up with its ability to disintegrate and thereby set free some of its atomic energy.

In the atomic bomb also there is a conversion of atomic energy due to the splitting-up of nuclei ; in this case the nuclei of plutonium. This reaction is not spontaneous, like the disintegration of radium, and consequently we can control its initiation.

The process occuring in the sun is of quite a different nature. Although the splitting-up of heavy nuclei, such as those of plutonium and radium, can lead to the conversion of atomic energy into other forms which can be used, the splitting-up of many light nuclei, notably the breaking-up of a helium nucleus into four hydrogen nuclei, actually involves the production of some atomic energy out of other forms of energy. (Atomic scientists will realize, of course, that the manufacture of hydrogen nuclei from a helium nucleus actually implies more than a mere splitting-up, but I do not want to complicate the argument.) If we reverse the process by building up helium from hydrogen, it should be possible to set free some atomic energy, that is, convert it into other forms which we can use. It may perhaps seem paradoxical that while in one case disintegration lowers atomic energy, in the other case it leads to an increase. Nevertheless, by considering the structure of nuclei in detail it is quite possible to arrive at a consistent explanation. However, this is too long a story to enter into now.

This synthesis of helium from hydrogen is, we believe, continually operating in the sun. It is scarcely feasible that this synthesis should occur simply through four hydrogen atoms coming together. Rather it would appear to take place in stages, a carbon nucleus acting as an intermediary in the process. The details are still somewhat speculative. The present theory postulates a chain of six nuclear reactions, which incorporate the hydrogen nuclei one at a time and set the carbon nucleus free again at the end, the net result being the combination of the four hydrogen nuclei into helium. We can equally well regard the process as beginning with nitrogen instead of carbon, but this is a matter of detail.

Adopting this theory of the sun's activity, it is not difficult to provide a reasonable account for the approximate constancy of the sun's temperature and energy output. I say approximate because disturbances of the sun's surface, notably sunspots, eruptions, etc., are of comparatively frequent occurrence, and appear to influence the amount of radiation. It seems likely that the sun's output will change relatively slowly over the next few millions of years. It will probably slowly increase at first but, after the lapse of many millions of years, it will drop and continue to drop until the sun is a cold star like the earth and all life is extinct. It is possible, of course, that at some earlier stage the sun will explode, as some stars have been known to do, and life would then be destroyed in a more sudden and spectacular manner. The sun is, after all, a large-size atomic bomb.

The energy that results from the synthesis of helium is very great, far greater than any ordinary burning of a comparable mass of fuel can produce.

The energy-output of the sun is obtained at a cost of less than a quarter of an ounce of hydrogen per thousand kilowatt-hours. The total consumption is large, amounting to three thousand billion tons (3×10^{15} tons) each year, but this is only about one billionth part of the

Energy Derived from Fuels.

Fuel	Form of Energy Utilized	Energy Obtained (KW-hrs per Kgm.)
Wood	Chemical	say 5
Coal	Chemical	say 10
Oil	Chemical	say 12
Plutonium	Atomic	say 30,000,000
Uranium-235	Atomic	say 25,000,000
HYDROGEN	Atomic	150,000,000

sun's total mass. We do not know precisely what proportion of the sun consists of hydrogen, but there is evidence that hydrogen must constitute an appreciable fraction of the total, so there is no need to fear the hydrogen supply running low for a few million years or so.

Since the earth, like the sun, is composed partly of hydrogen—about one per cent. of the earth's crust consists of this element—one is led to consider whether there is any chance of setting-up, on the earth and under our control, a machine in which hydrogen, in relatively small quantities, could be converted into helium. Such a process could not be made to occur spontaneously, for there are decisive factors which prevent this, but it is conceivable that some process might be devised. We should want one different from the solar process ; it could not be considered because of the enormous temperatures involved. We want then some other process leading to the synthesis of helium from hydrogen.

Such a process, if successful, might provide us with all the energy we need at a comparatively small cost in hydrogen. Taking a figure of ten thousand million kilowatts as the outside estimate of our demands, this corresponds to a consumption of somewhere about a ton of hydrogen per day. As the oceans alone contain about a hundred thousand billion tons (10^{17} tons) of hydrogen, this consumption could scarcely be regarded as excessive. In fact, nearly as much hydrogen is probably being wasted at the present time by the escape of hydrogen gas resulting from the electrolysis of water.

Naturally we could hardly expect 100 per cent. efficiency from our machine, *i.e.*, we could hardly expect all the atomic energy-reduction to appear as useful energy. Further we should have to employ a considerable amount of useful energy in making the machine itself. Even if we had an overall efficiency of only one per cent., however, the consumption of hydrogen could scarcely be regarded as serious.

You may wonder why, when we have a source of energy ready to hand in the plutonium bomb and the nuclear fission pile used in making it, I have stressed the importance of the hydrogen process. The fact is that while the first development of atomic energy machines, using uranium and thorium as the raw materials, may provide an immediate solution to the pressing problems of fuel shortages, it cannot be regarded as anything but a temporary solution. This is due to the fact that the high-grade ores of uranium and thorium will almost certainly be rapidly exhausted ; in fact, the atomic bomb manufacturing programme of the United States will probably exhaust them before the end of the century. Low-grade ores may still be used—they almost certainly will be used for atomic bombs unless a better bomb is invented in the meantime—but their use will not be profitable in terms of energy. Precisely at what stage the process will cease to provide an energy-profit cannot of course be predicted.

If the long-term solution must lie in a hydrogen-helium process, how are we to discover a suitable process ? There is no obvious line of attack. For this reason the Atomic Energy Establishments of Britain, France and the United States, together with University and other research laboratories, are devoting their activities very largely to quite general researches into nuclear physics. Only by the process of slow compilation of information concerning nuclei and their behaviour, only by the elucidation of their fundamental properties and the phenomena connected with them, can we hope to make progress. The solution, when it comes, is more likely to result from some apparently quite irrelevant research than from a straight-forward attack on the problem.

This is the reason why physicists are impressed with the importance of nuclear research ; this is the reason why they are sometimes somewhat impatient of the apathy, even obstruction, with which their proposals are often received. Those who, because of the belief that nuclear research necessarily means military research, or for personal or political advantage, oppose or obstruct nuclear research, are doing a very real disservice to mankind. If all the peoples of the world are to possess and maintain a standard of comfort and luxury such as the more fortunate peoples now enjoy, the energy supply problem must be solved, and must be solved soon.

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