INTRODUCTION TO ROUND-TABLE DISCUSSION ON BIOENERGETICS OF TOMORROW

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Shortly after the appearance of the second announcement of the FEBS Meeting, I received a letter pointing out that a method introduced by the writer of the letter would play a big rôle in future research in bioenergetics and that it would be very appropriate to include it in a Round Table Discussion on Bioenergetics of Tomorrow. I am sure that he is right, and his letter made me realize that the title that we had given to this round-table discussion was at least misleading, if not pretentious. For this, I apologize.

I hope, in any case, that since the publication of the list of speakers everyone now understands the purpose of this discussion, and that the chance of misleading bioenergetics can no longer be levelled at the organizers, even if the other reproach can still be made. The intention was, in any case, to discuss the rôle that bioenergeticists can play and I believe must play in solving the energy crisis. This is not the greatest problem facing us. That is the population growth, and unless we can solve that one we are headed for disaster anyhow. However, even if we do succeed in stabilizing the population at a level not too much larger than the 4 thousand millions that at present inhabit the earth, we shall still have to find enough energy for them to survive more than a few hundred years or so.

Since virtually all the energy that we use is derived from the sun by a bioenergetic conversion it is not too pretentious for the bioenergeticist to claim that he has something to say about the problem. Its magnitude is clearly expressed in the following figures.

To stay alive the average man (including babies and children in the average) needs about 2000 kcal per day in the form of food. This is equivalent to about 100 J per second, that is a continuous input of about 100 W or the same as a fairly large electric light. This amount of energy is sufficient to make about 1.4 mmol ATP per second.

Considering what man can do, 100 W energy expenditure does not seem much. He is, in fact, a very efficient machine. However, since there are 3.8×10^9 of us, the world population already needs the continuous production of 3.8×10^{11} W in the form of food. This energy is derived from solar radiation which has been absorbed by the chlorophyll in the chloroplasts and used to synthesize carbohydrates and other foodstuffs from carbon dioxide, water and nitrogen. We eat these plants or animals that have eaten plants.

The agricultural production in the world is just about sufficient to supply this 3.8×10^{11} W continuous energy, and it could be geared to produce a little more, but not very much. It is painfully obvious that it will not be able to support the exponentially growing population much longer.

This amount of 100 W is, however, only sufficient to keep a naked man alive and reproducing. He needs a lot more energy to be clothed, stay warm in winter or cool in summer, live in houses, enjoy himself and to travel other than by foot. The total energy consumption over the whole world is about 17 times as much, in prosperous countries like the United States 100 times.

It may seem paradoxical that man is reaching the limits of the possibilities of growing sufficient food, but at the same time is consuming 17 times (100 times in advanced countries) as much energy for non-vital purposes. This is especially so when we consider that the non-food energy that he is consuming was also laid down as a result of the ability of chlorophyll-containing energy-transducing membranes to convert solar energy into combustible fuel. The coal, oil and natural gas that we now burn is derived from the carbohydrate of forests growing millions of years ago.

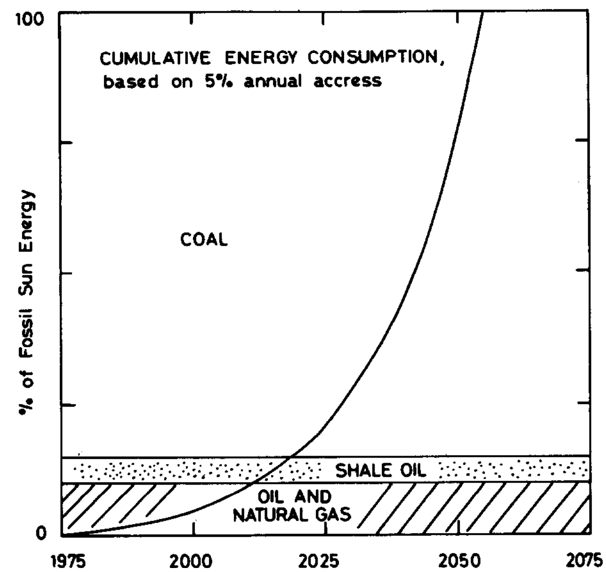

Fig.1. Cumulative energy consumption, based on the estimated present consumption and a 5% annual increase, expressed as a percentage of the estimated reserve of fossil sun energy present on the Earth. The cross-hatched and stippled areas indicate the percentage of these reserves in the form of oil and natural gas, and shale oil, respectively. The remainder is coal.

This fossil sun energy is our energy capital and we are using it up now at a rate 17 times faster than our solar-energy income derived from our present agriculture.

Our total reserves of fossil sun energy are about 1000 times our present yearly use. This seems, at first sight, a reassuringly large amount. However, the simple graph in fig.1 shows that it is alarmingly small. In the first place, only 10% of these reserves are in the form of oil and natural gas, another 5% is in the form of shale oil and the remaining 85% in the form of coal, much of it difficult to mine. Secondly, the world consumption of energy is (or was until very recently) increasing at the rate of about 5% per year, and it is difficult to see how this can be reduced much in the next decades, given the increase in the world population and the desire for increasing living standards among the poorer populations. Even a relatively small annual accretion of 5% has frightening effects over quite a short period, measured by the lifetime of man. Unless we do something about it, already by 2010, reserves equivalent to all our oil and gas would be gone, the reserves of shale oil would follow a few years later and in 80 years, within the lifetime of some of our grandchildren, everything would be gone.

Of course, we must do something about it. The first requirement, if an enormous catastrophe is to be prevented, is to stop the population increase. If we cannot do this, we are finished anyway. Even if we are successful, however, we have to find new forms of energy and, if we would like man to continue to enjoy this planet for a few hundred years more, new sources of energy income will have to be sought.

In the short term, we might use up some other energy capital to give us time to work out ways of increasing our energy income. Theoretically, geothermic energy, revealed to us in hot springs and volcanos, might be used. It has been estimated that these stores amount to about 80% of the fossil sun energy (see fig.2). However, we do not know yet how

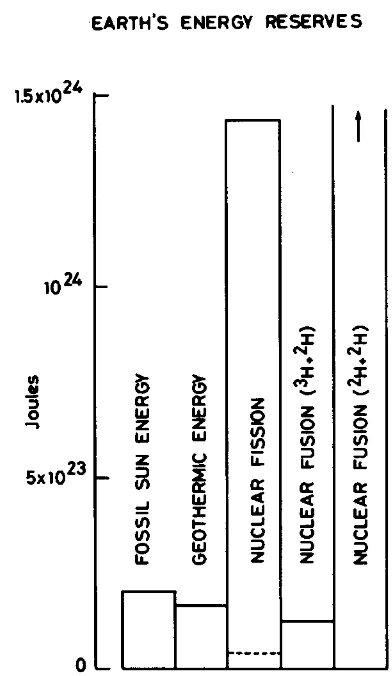

Fig.2. An estimate of the Earth's energy reserves. Two calculations have been made of the reserves of fissionable material (uranium and thorium), both on the assumption that it is economically and politically feasible to build breeding reactors. The higher estimate makes the additional assumption that it will also be possible to extract uranium from the sea, the lower (shown by the dotted line) that it will not.

to tap this source. We do know how to use the energy made available by splitting heavy atoms, and, despite the political dangers, it seems inevitable that we must introduce nuclear reactors on a large scale. However, the amount of thorium and uranium is limited and, with the reactors now in use, only sufficient to supply the world with energy at the 1975 rate for about 3 years, unless uranium can be obtained from the sea. This becomes financially feasible only if the energy yield of the reactors is increased, by the use of breeding reactors. In that case, the total reserves of uranium and thorium are equivalent to about 7 times our fossil sun energy. If it is not possible to extract uranium from the sea, it is only one fifth the amount of fossil sun energy.

Theoretically, it is possible to obtain energy by the fusion of light atoms, e.g. deuterium with tritium. However, tritium has to be made from lithium, and this is also present in restricted amounts, sufficient to yield energy equivalent to about 60% of our fossil sun reserves. The fusion of deuterium and deuterium would give virtually unlimited reserves of energy and if the physicists ever succeed in this they will have made a sun on earth, and the energy crisis will be over.

In case they do not, however, and until they do, we have to make use of the sun we have. This is our energy income. (It is true that we can harness the wind and the tides, but these can at best make a very small contribution to our total needs.) The earth receives 1.3×10^{17} W radiant energy from the sun, 20 000 times our present total consumption. And it sends out this energy whether we use it or not, so we are not robbing future generations by using it now.

We can harness directly the heat of the sun, not only for heating houses, but also to drive electrical turbines or to split water into hydrogen and oxygen. But this is rather costly and the bioenergeticist would like to copy the way nature does it. It is indeed perfectly feasible to allow a chloroplast suspension to reduce a low-potential dyestuff with reducing equivalents derived from the photolysis of water (the oxidizing equivalents are evolved as oxygen) and to feed these reducing equivalents to hydrogenase which converts them to molecular hydrogen. The system chloroplasts + dyestuff + hydrogenase can bring about the photolysis of water to hydrogen and oxygen. Hydrogen is, in many ways, the ideal fuel since the product of its combustion is water.

More research on the efficiency of the energy conversion and on means to stabilize the catalysts, either extracted from living material or made in the chemical factory, is required before the technological feasibility, in particular the cost, can be assessed. The first three speakers this afternoon will direct themselves to this aspect.

The next two will deal with the observation that, in sunlight, certain bacteria (growing normally where the concentration of salt is high) can produce an electrical potential across the cell membrane. This also deserves exploration as a possible method of utilizing solar energy.

I hope that the speakers, and those contributing to the general discussion, will give attention to the gaps in our knowledge of bioenergetics that will have to be filled before the bioenergeticist can talk to the engineer, so that these theoretical possibilities can be tested in practice.

Man does not have much choice. Either we trust the physicist to make us a sun without blowing us up, or we let the bioenergeticists use our present one. Otherwise, we won't last more than a hundred years or so.

This is an exciting challenge for the bioenergetics of tomorrow.