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FUTURE SOURCES OF POWER[1]

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THE sun's rays shower as much energy on the earth's surface in one minute as the entire human race utilizes in one year. Despite the presence of this bountiful and unusual flow of energy, a large part of the struggles of the human race are concerned with acquiring and controlling sources of power. Evidently our state of development in the utilization of power is still rather crude. A review of the various practical sources of the present day is in order.

PETROLEUM

The energy supply which is most critical in America is that of petroleum. At the present time we are using considerably over a billion barrels per year. The known proved reserve of petroleum in the ground is 14 to 17 billion barrels, depending on who does the estimating. Thus the petroleum actually in sight is only about a twelve-year supply. But new discoveries are being made constantly so most of the people in the petroleum industry say they are not worried about the supply, at least for the present generation. It is a little discouraging to note, however, that the new discoveries are not quite keeping pace with use so the pinch of partial depletion may come sooner than the optimists anticipate.

There may be discoveries of great new fields, but the prospects of that are not very good. There is the possibility of extensive fields lying under the ocean

[1] Summary of an address before a joint meeting of the Rochester, Syracuse and Cornell sections of the American Chemical Society, Rochester, N. Y., October 4, 1941.

next to coastal plains such as border the Gulf of Mexico. There may also be a great deal of petroleum at far greater depths than are yet explored. We live in hopes that there are, but it should be remembered that if recovery is made from the more difficult places, the cost of production is certain to rise and the customer must pay for it.

Technical advances in refining have greatly extended the potential life of the petroleum resources. The wide-spread utilization of cracking has more than doubled the yield of gasoline and hence has more than doubled the potential supply of motor fuel. Now the polymerization of refinery gases into liquid fuels is beginning to come in and is helping to extend the life line of petroleum. Such technical advances are a great factor in keeping up the liquid fuel supply, but eventually, perhaps distressingly soon, the pinch of depletion will begin to make itself felt. What then? There are several possibilities that need to be evaluated.

I. *Getting all the petroleum out of the ground.* Even with the best production methods, over half the original petroleum deposit still stays in the ground after the well has gone dry. Mining of the sands seems to be impractical, not to mention being very expensive. If some one will devise an inexpensive means of breaking the adsorptive forces between petroleum layers and the sand grains, he will greatly lengthen the life of our oil resources, not to mention the possibility of making himself rich.

II. *Shale oil.* There are many billions of tons of oil shale in this country which when heated will yield from half a barrel to two or three barrels of petroleum-like oil per ton of shale. The potential supply is enough to supply our motor fuel for from 100 to several hundred years, depending on the grade of shale considered acceptable. But mining or quarrying the shale, retorting it and disposing of the waste costs effort and money. If the refinery cost of gasoline should double above its present figure of 5 to 6 cents per gallon then shale oil might begin to compete. Thus we have a considerable back log of motor fuel, but we will only get it by paying higher prices than at present.

III. *Hydrogenation of Coal.* Germany and, to a certain extent, England are making fairly satisfactory liquid fuels by reacting hydrogen gas with low-grade coal at high temperature and pressure in the presence of a catalyst. But the cost of production is about 20 cents a gallon compared to the American cost of 5 to 6 cents a gallon from petroleum. That high cost might be lowered somewhat, but the prospects are that it will not go down materially. Thus we can drive our cars on motor fuel from coal, but we'll have to pay dearly for it.

IV. *Alcohols from Agricultural products.* This is great fuel for politicians from the corn belt but not so practical for automobiles. The first item is cost—15 to 20 cents a gallon under best practice; next, lack of supply—a small fraction of our fuel might be supplied from waste and surplus farm products, but it would require nearly all the good crop land in the country to supply our motor fuel demand by this means. There wouldn't be anything left to eat.

Summarizing liquid fuels: We can have fuel for automobiles for at least several generations but at a price. The lush days of practically free oil from the ground will begin to end some of these days—probably too soon to please us. This generation may very well feel the pinch of partial depletion. Any economy or conservation steps are very much in order.

V. *Duplication of Geochemical Reactions.* Dr. Ernst Berl at the Carnegie Institute of Technology has succeeded in making liquid and solid fuels which are close duplicates of our petroleum and coal, using natural carbohydrates such as sugar as the starting material. He has apparently duplicated and greatly accelerated the geochemical reactions which produced these fuels. If we are to supply part of our fuel demands from current vegetation, Dr. Berl's work may be the best starting point.

Coal

In coal we are the most happily situated country in the world. We have over half of the world's known coal reserves; less than 6 per cent. of the world's population. At the present time we have enough coal in sight (all grades) to last 3,000 years. That picture may change if the other 94 per cent. of the people of the world decide that we must divide up, but that is one of the unpredictables. Hence as regards coal we may say that we are very lucky. But that doesn't mean we should be negligent of conservation. Within the next hundred years many of the best deposits will be depleted. We will have to begin depending on the lower grades. Expenses of recovery will go up, quality will go down. It will be wise to extend the life of our A-1 deposits as long as possible.

Eventually, no matter how much we conserve, this sponging off past ages for fossil energy must cease—the deposits will have gone up in smoke. What then? That's a question which America will face eventually, which many groups of people in the world are facing right now. Other possible sources of energy certainly should be considered.

Other Sources of Power

I. *Water power.* The water power sources of the world are by no means fully developed, but even if they were they would be quite inadequate. About 10 per cent. of America's energy comes from water power. By full development that could be extended to 20 or 25 per cent. It helps, but it simply is not enough.

II. *Wind.* Lots of energy goes to waste in a hurricane or tornado, but you can't count on it. The winds are not dependable even in Kansas. Moreover, the average breeze is at a very low potential as far as energy is concerned. Except for isolated, special cases where a high-cost storage capacity can be provided, wind power seems to be out.

III. *Tides.* In a limited number of places, such as ill-famed Passamaquoddy Bay, the use of tidal power may be practicable if a possible market is close at hand. Like the power from falling water, this may help, but it can supply only a small proportion.

IV. *Wave power.* Many wave motors have been designed; some of them have been patented. But the item of variability of the source of power seems to relegate this device to the impractical heap.

V. *Utilization of current vegetation.* About fifty times as much energy is stored up in plant life on the earth in one year as man utilizes in that year. It might then appear that we could use the present growing trees, grasses and shrubs for fuel and then solve the problem. Close investigation makes that idea discouraging. In the United States we would have to use nearly all our annual crop of vegetation (trees, grass, farm crops) to meet the energy demand. Nothing would be left to eat, and the land would all be a desert in a few years. We can't push vegetation very far from its natural cycle. All the data shows that we can not go back to a tree- and brush-burning economy.

VI. *Atomic energy.* The business of smashing atoms to release great gusts of energy is a profitable sport—for news reporters. Radioactive materials, of which there are only minute amounts in the earth, disintegrate and slowly release large amounts of energy. If radium, for instance, were as plentiful as copper, atomic boilers using radium as fuel might be practical, but there just isn't very much radium available. Recent work has shown that one of the isotopes of uranium, U_{235}, upon bombardment with slow neutrons, will disintegrate to give a net yield of energy equivalent to the burning of 3,000,000 times the same weight of coal. But separation of this isotope, U_{235}, has not yet been accomplished except in sub-microscopic quantities. Any other materials tried have not thus far shown any hopes for energy production. Thus any Atomic Energy Development Company seems to be facing a stone wall of discouraging facts. One can not arbitrarily say that we will never be able to get energy from atomic disintegration, but in our present forecasting we will be on safer ground if we don't count on it.

DIRECT UTILIZATION OF SOLAR RADIATION

This brief survey has not answered the question of where we will get our energy, but it has pretty well covered the possible sources—excepting one—the direct utilization of the energy of the sun's rays.

The average intensity of solar energy in this latitude amounts to about 0.1 of a horse power per square foot. The energy falling on one square yard of roof would more than operate all the electrical household appliances, including lights, of the average family—if it could be directly utilized. Most factories have energy falling on the roof to operate all the machinery in the place—if the management had enough ingenuity to utilize it. No one has developed that ingenuity yet.

Photoelectric Cells. One of the obvious possibilities for direct utilization of solar energy lies in photoelectric cells. Thus far photoelectric cells have operated with microscopic efficiency and have been very expensive. If some one can make revolutionary improvements in photoelectric cell efficiency and can cut the cost of construction away down we might have something there. At present the prospects are discouraging, but one hesitates to say such utilization is forever impossible. Even with the items of efficiency and cost brought under control, the matter of storage of energy during periods of darkness would be troublesome. Large storage reservoirs of water might solve this problem, pumping water to high levels in daylight hours, using it in water turbines during darkness. The overall efficiency of such storage can be about 70 per cent. In general, it may be said that photoelectric cells are barely possible but not hopeful.

Solar Boilers. The simple and obvious device of using focussed sun's rays to heat up a liquid has been toyed with for a long time. Solar-boilers of various degrees of impracticality have been the child of many inventors' minds and the subject of many patents. Dr. Abbot, of the Smithsonian Institution, has a small solar power plant with revolving parabolic mirrors for which he claims an electrical energy production efficiency of 15 per cent. We'll have to do better than that if the sun's rays, which are not at very high intensity to begin with, are to be a practical source. It is not likely that the efficiency of the solar power plant, if it operates by steam generation, can be greatly improved.

On the other hand, solar energy may very well be on the verge of being practical for heating of buildings where a high potential is not important. The storage capacity must be sufficient for weeks or even months of operation. A basement full of hot water, periodically reheated by sun's rays, might be possible, but it hardly sounds practical. I would think that a closed cycle of employing a low-boiling liquid might better serve for such storage. First costs would be high, but operating costs might be cut to the vanishing point.

Such an idea may bring a smile, but it is now becoming almost respectable, for the Massachusetts Institute of Technology has begun some experimentation along this line.

Photochemical Reactions. The foregoing suggest some interesting ideas, but with the exception of heating buildings, they do not seem to come within a gunshot of practicality. I have saved what I consider to be the best idea until the last. Namely, men should try to do efficiently what nature has been doing inefficiently for a billion years—utilize photochemical reactions. The basis of all life is some simple photochemical reaction as

$$H_2O + CO_2 + \text{Radiant Energy} = \underset{\text{Formaldehyde}}{HCHO} + O_2$$

The formaldehyde may be thought of as forming simple sugars, which then serve as the basic material for the multitude of complex compounds in plants. I realize that the actual photochemical reaction is much more complicated than this and that the formaldehyde theory is no longer tenable, but I am using this as the simplest picture to illustrate the point. What we should like to do would be to take some such simple compound as formaldehyde formed with the help of radiant energy, put it in an electrochemical cell, expose it to oxygen, and then reverse the above reaction and get back the stored energy as electrical energy—at high efficiency. Formaldehyde *can* be oxidized in a cell in a basic solution to give formic acid and a small amount of electrical energy. Perhaps all that is needed is a proper catalyst to complete the oxidation to CO_2 and water and get back nearly all the stored energy.

The catalyst which nature used for performing the photosynthesis of the above equation is chlorophyll. That's the best catalyst known, but it's very poor. Plants are very inefficient storers of energy. Even the most luxuriant plants have an energy storage efficiency of less than 2 per cent. We ought to be able to do a lot better than that.

It's a wide-open field, this study of photosynthesis and the study of oxidation cells which will reverse the reaction. That's the reason it's hopeful. The systems which might be used would not have to be limited to organic compounds. It may well be that inorganic compounds offer the most hope. The satisfactory system would need to be one that is as light-sensitive as the chemicals on a photographic film, as easily reversible as a lead storage cell. If such a photochemical-electrical system can be developed the problem of energy capture and storage would be solved. The storage of the energy would be simply that of storing chemical compounds. We're used to doing that with coal.

CONCLUSION

Some day the photochemical approach to energy utilization will either be solved or definitely proved impracticable. In view of our own energy resources it may seem foolish to start working on it now. But it may not be too early to start. If we wait too long we may be caught short as energy supplies dwindle. Moreover, many parts of the world already suffer from insufficient energy. Many international problems might disappear if every group of people could fully utilize the energy falling on its roof-tops.

Enough energy falls on about 200 square miles of an arid region like the Mohave Desert to supply the United States. When we become ingenious enough to efficiently utilize the energy treasure wherever it may fall, we may solve many of our economic problems. It might be a little hard on the railroads that haul coal, but every one else would benefit.

A PRACTICAL SYSTEM OF UNITS FOR THE DESCRIPTION OF THE HEAT EXCHANGE OF MAN WITH HIS ENVIRONMENT

By Drs. A. P. GAGGE, Yale University; A. C. BURTON, University of Toronto, and H. C. BAZETT, University of Pennsylvania

THERE are three groups interested in the thermal exchanges of the human body, namely, the heating engineers, the physicians and the physiologists. In the English-speaking countries each of these groups by training uses a different set of physical units. The heating engineer uses B.T.U., square feet and °F., the physician calories, square meters and °F., and the physiologist calories, square meters and °C. Consequently they find it difficult to make themselves mutually understandable when discussing their common interest of heat exchange. It is our proposal to present a system of units such that all three groups may think in terms of a common and at the same time a practical system.

Thermal comfort in any environment is dependent on many variables. There is evidence that in the final analysis comfort is dependent largely upon skin temperature. The optimal average skin temperature for