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THE PRESENT AND FUTURE STATE OF OUR NATURAL RESOURCES[1]

ALMOST nineteen years ago I set foot for the first time upon American soil, and it is most interesting, after so long a time, to now renew acquaintance with American life and American universities. Much has happened since my first visit to the United States, and the World War has in many ways revolutionized our ideas, whether for better or for worse. One American characteristic, however, has evidently not changed, and that is your cordial hospitality, which I find to be as warm to-day as it was twenty years ago.

I wish first of all to express my very sincere appreciation of the honor of the invitation to come to Cornell University as an incumbent of the George Fisher Baker Non-resident Lectureship in Chemistry, that splendid endowment which can not be too highly prized, because it affords your students what we in Europe regard as one of the most important features of university life, namely, frequent contacts with investigators from foreign countries and with workers in various branches of science.

It was with great pleasure that I accepted the invitation tendered to me by the trustees of this university and by Professor Dennis and his colleagues, and my earlier experience in America convinces me that my stay at Cornell will remain one of my most pleasant recollections.

It has become a custom for your guest to devote this introductory lecture to the presentation of some topic of general interest which is not necessarily related to his later technical lectures, and I have chosen for my subject this evening "The Present and Future State of Our Natural Resources."

This is a question of great general interest, and is one in which the chemistry of our day is deeply involved. Archeologists have distinguished the different principal periods in the history of human civilization in a particular way, and have employed the terms the stone age, the copper and bronze ages, the iron age, etc., expressing in this manner their deep conviction that the state and future of the human race is, at every moment of its history, intrinsically connected with the special position in

[1] Introductory public lecture by Professor F. M. Jaeger, of the University of Groningen, non-resident lecturer in chemistry at Cornell University.

which man has been able to place himself with respect to his natural resources of materials and energy. This is true not only for the past, but equally so for our present-day world.

If we speak of "natural resources" in the most general sense of the word, we have in view both the material and the energetic resources of nature. The first are represented by the small or more extensive stocks of materials of varying kinds; coal, oil, iron, tin, ores of the heavier metals, many mineral and vegetable products, as potash, rubber, etc. Resources of energy, on the other hand, are certain natural stores that can directly be utilized for the production of mechanical force, or can easily be transformed into special forms of energy that can then be thus used. Waterfalls, the high and low tides of the sea, and solar radiation are examples of such resources of energy. It is not always possible to draw a sharp line of demarcation between the two categories, because "matter," as such, always represents also a certain stock of potential energy. Coal and oil, for instance, are only in small part utilized as raw materials; in by far the greater number of cases they are used as fuel, their energy of combustion being applied in our engines.

Let us now first consider the material resources. Everybody knows that our whole technical and industrial development depends upon the use of a certain number of indispensable raw materials. Technics and industry in their present aspect would be obliterated if the natural sources of supply of such metals as iron, copper, tin, lead, zinc, etc., should suddenly become completely exhausted. Dynamo and steam engine would in that case irrevocably disappear, just as the monsters of earlier geological epochs, the ichthyosaurus and the megatherium, vanished as soon as conditions became incompatible to their existence. Industry and traffic in their present form would become quite impossible. And the same is true, if the stores of coal and oil were no longer at our disposal. Attention has repeatedly been drawn to the fact that the danger of such a catastrophe is not very remote if we continue to squander our capital of raw materials in the reckless way that has been pursued in the past and indeed is even now being followed.

Jeans has recently sharply emphasized the fact that humanity in its present stage of development must, properly speaking, be considered as a "baby" only, if the still vast future existence of our race is taken into account—a baby, which hitherto has chiefly thought only of its nutrition and first physical growth, and which but recently has begun to look somewhat farther than its immediate environment. We must, however, acknowledge that during this very insignificant portion of its whole presumable existence, that same baby has already shown that it is extremely gluttonous, because in only 120 years it has fed on its natural resources in such an immoderate way as to cause anxiety concerning its future nourishment. All countries are now beginning to understand that the material resources of the world are by no means inexhaustible, and that it is urgently necessary to take measures to prevent further unrestrained destruction of them. Some numbers and graphs may help to elucidate the present situation.

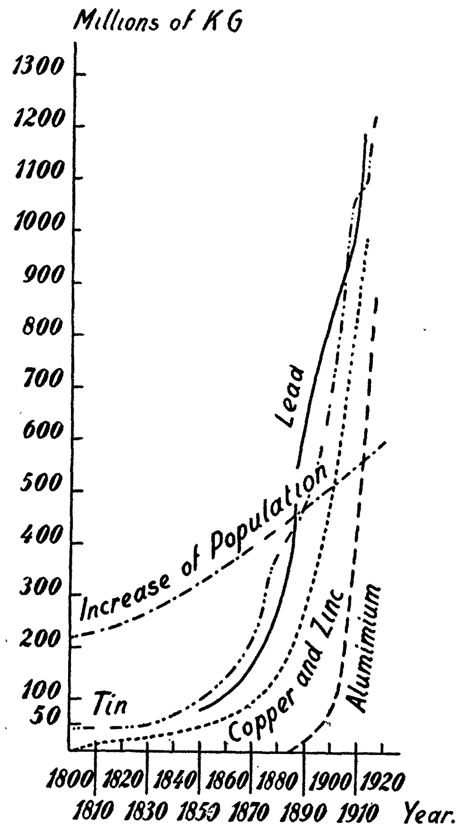

Fig. 1. Yearly increase of consumption of some Metals during the last 120 years.

In 1878 the annual world production of copper was 154 million kilograms; in 1892 it was 310 million; eight years later 713 million, and in 1917 1,413 million kilograms, about ten times the amount produced in 1878. Thus we see that the production of this metal has doubled about every nine years.

The annual world consumption of coal in 1840 was about 50 billion kilograms; in 1860 it was 200 billion; in 1880 460 billion, and in 1920 it had increased to 1,550 billion kilograms, or thirty-three times the consumption in 1840.

In 1860 about 96 million liters of mineral oil were produced; in 1870 eleven times that amount; in 1880, sixty times, and in 1890 one hundred and fifty times that quantity. The present consumption has risen to the enormous figure of about 214 billion liters a year. The United States alone produces about three quarters of this tremendous quantity, and measures are now being taken to keep it stationary.

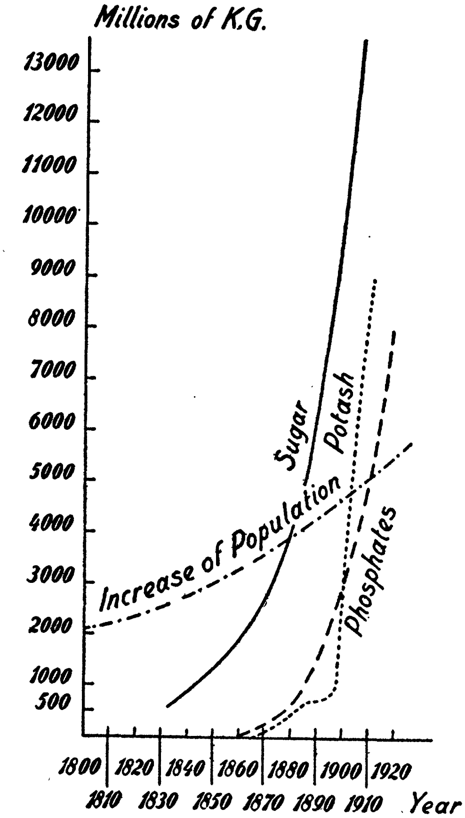

Fig. 2. Yearly increase of consumption of Sugar, Phosphates and Potash during the last 120 years.

In the same period of sixty-eight years, the production of Chile saltpeter has increased to one hundred and thirty times the original quantity; it is now about three billion kilograms a year.

The three graphs will give you an idea of the general rates of increase of the yearly consumption of several important metals, coal, sugar, phosphates, potash, etc., and of the analogous form of the corresponding curves in all cases. In some of these graphs there is also given a curve which indicates the increase of the world's white population. The striking difference between these two curves clearly shows that the yearly consumption of raw materials *per individuum* has increased in quite an alarming way. In Figure 4 the curves give a direct and impressive graphical representation of this increase of what I might call "the individual hunger for raw materials" of the present world.

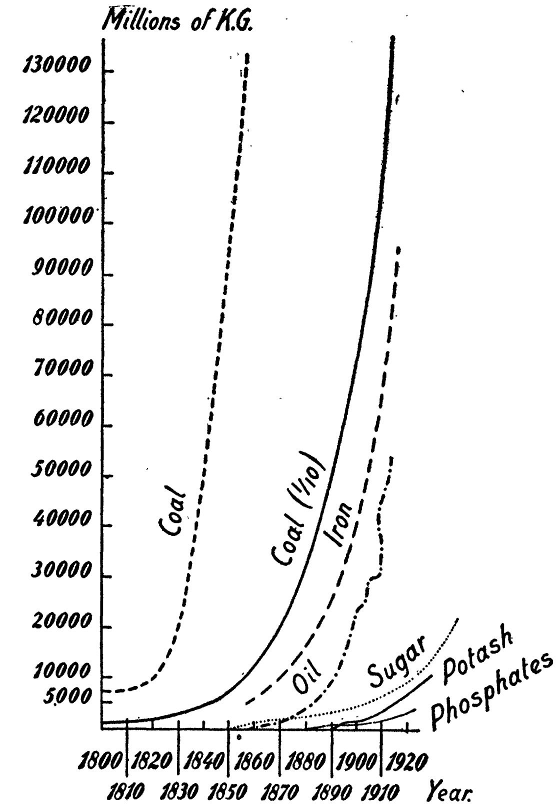

Fig. 3. Yearly increase of Coal, Iron and Oil during the last 120 years.

Many authors have already often emphasized the fact that if this rate of consumption continues, the world demand will increase within a hundred years to such enormous quantities that it will far surpass the available amount of some of these materials, such as tin and oil.

Perhaps some of you might raise the objection that, according to one of the fundamental laws of chemistry, matter is indestructible and that the quantities produced must, therefore, continue to remain in circulation. But this law is not applicable to our economic life because great quantities of these materials are forever lost every year by "wastage," and thus are withdrawn from circulation in forms from which they are not recoverable. This is true, as everybody will immediately grasp, not only for such substances as coal and oil, which are completely destroyed, but also for a great number of compounds

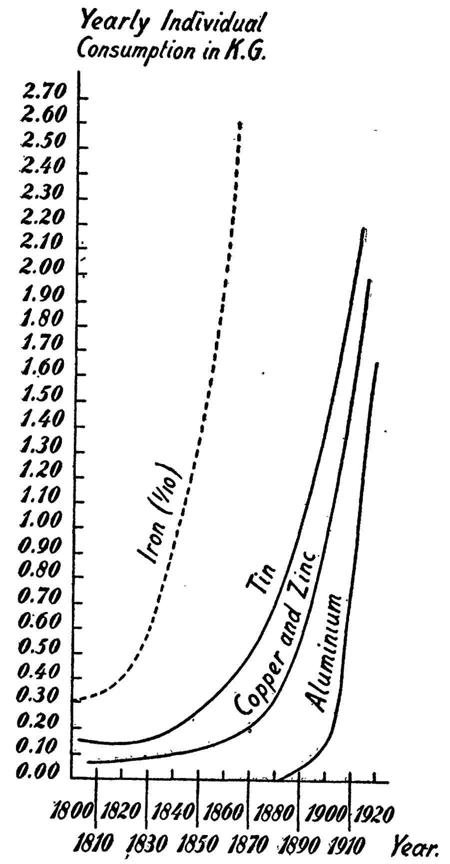

Fig. 4. Yearly Increase of the Consumption per Individual during the last 120 years.

of lead, zinc, tin and other metals, which, in the form of pigments or other chemical combinations, pass into the wastes of many industries and thus finally reach the sea. Very appreciable quantities of even the metals themselves are steadily lost beyond recovery.

As early as 1911 Sir William Ramsay, on the occasion of the meeting of the British Association for the Advancement of Science at Portsmouth, called attention to the fact that if English coal mining should go on at the rate of that moment, England, within 175 years, would no longer be able to provide itself with coal. B. W. Evermann in 1922, in an address before the American Association, gave a survey of the deplorable destruction of the forests of the United States, emphasizing the influence of it upon the water content of the rivers and on the change of the fauna in them. Several geologists are of the opinion that the stores of oil in the United States will, if consumed at the present rate, last no longer than forty or fifty years.

In 1921, upon the recommendation of the National Academy of Sciences, the American Association for the Advancement of Science and the National Research Council in this country, an Executive Committee on Natural Resources was created. This committee plans to make a continuous survey of the stocks of raw materials still present in America. All these facts clearly indicate that at last the conviction is more and more gaining ground that this vital question of supply needs to be kept constantly in view, and that we must give careful study to the methods by which the raw materials necessary for our economic life may be rendered independent of the limited natural stocks of them, accumulated in former geological epochs.

The answer to this question must principally be expected from scientific and more particularly, from physical and chemical research. In this connection permit me to draw your attention to the enormously increased production and the simultaneous decrease in the consumption of coal in the blast-furnace industry, which was achieved only after long and painstaking systematic research of this and related processes in the laboratory; to the development of a number of synthetic methods which now enable us to meet the alarming deficiency of those natural nitrates that are so indispensable for agriculture; to the gradual replacement of natural gasoline as a liquid motor fuel by synthetic alcohol and by "artificial" gasoline, the production of which in 1928 by the Farben Industrie of Germany alone amounted to one hundred million kilograms a year, while for 1929 it is estimated that the quantity will be doubled. The problem of the most economic way of using coal in industry and as a fuel is being studied on all sides in a number of laboratories specially equipped for that purpose. New possibilities, be it by the improvement of existing methods or by the development of completely new ones, are created every year in scientific and industrial laboratories. Numerous tests are continually being made as to the possibility of replacing many raw materials, hitherto considered indispensable, by others which will do as well or even better than the old ones. Thus, for instance, the use of metallic aluminum and its alloys for constructive purposes instead of the often more costly, heavier metals has increased very rapidly during recent years. In industry, and to a certain extent also in our daily life, measures are now taken to avoid the dissipation of raw materials by making use, in an appropriate way, of waste products formerly considered as valueless. It is worth remarking that an undeniable change of direction can be seen in the choice of raw materials for all kinds of purposes. The effect of this change is that the heavier metals, which, in general, are obtained by mining at the lower levels of the earth's crust, are being replaced by the less dense metals and other elements that are present in the upper layers of the lithosphere, and which, therefore, may with much less cost be obtained by surface-mining. Among those elements silicon, which in the form of silica represents 60 per cent., and aluminum, which, as its oxide and as other compounds, represents about 15 per cent. of the earth's crust, are, with calcium and magnesium, the most predominant ones. I have already mentioned the enormous yearly increase in the application of aluminum. Recently an alloy of this metal with silicon, termed "silumin," has been brought upon the market for construction purposes, and is replacing iron in many cases. In this connection let me further draw your attention to the fact that the use of concrete and Portland cement, for the same purposes, is increasing yearly at a gigantic rate, and the glass and other compounds of silica are now used in many cases where formerly metals were employed. That this change of direction necessitates the solution of many totally new chemical problems need hardly be emphasized. Let me only remind you here of the possibility of extracting metallic aluminum, not from bauxite but from the various kinds of ordinary clay which are everywhere immediately at hand on the earth's surface and, therefore, represent a much cheaper material.

Thus, it is again the quiet research work of the chemist in his laboratory, the results of which do not always seem to lead immediately to practical applications, which in the end prepares the fertile soil from which we shall be able to reap the technical and industrial victories of the future. As Lord Cecil remarked some years ago, it is principally by new conquests of nature that our society can gradually reach a higher level of life. Indeed, at the present time, as Sir William Bragg recently emphasized in his address to the British Association in Glasgow, industry is the slave of pure scientific research rather than its master. Every far-seeing government must set itself the task of supporting this scientific investigation by abundant endowments, because only new discoveries and their applications will be able to avert from mankind the ominous menace of an early shortage of our material resources, and the consequent impoverishment of our civilization.

Let us now consider the second category of natural resources, the energetic ones.

It is a well-known fact, that, both for the biological processes in plants and animals as well as for the maintenance of human civilization, a continuous import of energy from outer space to our planet is necessary. The only source of energy that practically needs to be taken into account in this respect, and which daily furnishes enormous quantities of energy, is our sun. In whatever form we meet with energy on the earth, whether it be stored in coal or oil, or be immediately available to us, as in the flowing or falling water, or in the winds, it can in all cases easily be understood that this energy has always its real origin in that of the radiation which the sun continuously emits in all directions into space. If this radiation is absorbed, it will for the greater part be transformed into heat, which causes the water on the earth to evaporate, and thus gives rise to the mighty formation of clouds. Inversely, the condensation of this water vapor is the cause of rain and snow fall, which in their turn feed the rivers, seas and waterfalls. The differences in temperature and pressure in the earth's atmosphere that are brought about under the influence of the solar radiation are the cause of air-currents which give rise to the energy of the wind. The radiant energy of the sun given out several hundreds of millions of years ago is now stored up in the form of chemical energy in coal, after having been transformed and accumulated in the living vegetable cells of those far-off eras. Through the process of combustion, this stored-up chemical energy is used by us in our steam engines and gas motors of to-day. This stock of coal, and also of mineral oil, nowadays represents the principal source of energy that man utilizes for the production of mechanical power. There is no other source of energy on the earth the output of which can even distantly be compared with that derived from the two sources just mentioned. We can safely say that practically our whole need of energy is supplied by that fossil stock of solar energy which is at present stored in our deposits of coal and oil. The necessary consequence of this is that we draw upon our energy capital to so great an extent that it must finally become exhausted, unless some way be found to replenish it by again accumulating this mighty solar radiation against the day when our stores of coal and oil will have been exhausted. The total quantity of coal on the earth seems not to exceed about 2,000 billion tons, of which at the present time about 1.5 billion tons are used annually. This yearly consumption, however, is increasing so rapidly that our coal deposits will hardly be sufficient for another thousand years, a period that is very short in comparison with the length of the future existence of mankind on the earth. But the exploitation of the coal deposits that still remain will become impossible long before that time, both for technical and for economic reasons. Within a period much shorter than these thousand years, the ominous consequences of the present reckless demolition of our coal fields will make themselves seriously felt, for the simple reason that the coal must be extracted from ever deeper and deeper levels with consequent rapid increase of the cost of mining.

The question as to whether it then will be possible to obtain the indispensable energy from other sources on earth must, so far as can now be judged, be answered in the negative. Again at the instigation of Sir William Ramsay, the possibility of such an eventual development of other energy sources was in 1910 seriously investigated in England by a number of competent men. On that occasion the possibilities were taken into account of making use of the ocean tides, of the internal heat of the earth, of the energy of the winds and waterfalls, of the kinetic energy of the earth's rotation and of its yearly motion in space, of the chemical energy of wood and peat supplies, and finally of the intra-atomic energy of the atoms of the elements.

This official inquiry showed that the application of the internal heat of the earth, of the kinetic energy of the earth's motions, of the energy of the winds, and the use of wood and peat supplies never would be of any significance for the solution of the problem in comparison to the enormous quantities of energy yearly furnished by our resources of coal and oil. The energy that could be obtained by the disruption of the atoms of our chemical elements would be enormous in amount, but we need not further consider it at this time because in the opinion of our ablest scientists the practical accomplishment of this objective will be achieved only in the far distant future, if ever.

The available water-power on the earth would, according to Engler, amount to about the energy of seventy million tons of coal annually, *i.e.*, to about 4 per cent. of the energy necessary every year. Of course, the total water-power present on earth is much greater, but an appreciable part of it will probably never be available. A calculation made in 1922 by Steinmetz seemed to indicate that the energy of the flowing water, corresponding to the yearly amount of rain in this country, would be almost equivalent to that of your yearly coal consumption. Spoehr, however, has emphasized that these calculations are totally theoretical, as a great part of that energy is inaccessible and the distribution of the remaining energy over such an extensive territory would meet with almost insurmountable difficulties. Therefore, in this respect, America is, for the time being, dependent in a large degree upon her own resources of coal and oil, of which the latter seems to be rapidly approaching final exhaustion, notwithstanding the apparently reassuring fact that new sources of limited extent are frequently being developed.

The possible use of the low and high tides of the sea has occupied the attention of various inventors since the fifteenth century. Indeed, the periodically alternating low and high ocean tides would furnish gigantic quantities of energy if it were only possible to use them for mechanical purposes in a not too expensive and complicated way. In recent times several solutions of this problem have been proposed, some of which have already found a practical application, although only on a relatively small scale, in France, in England and in several places in Germany (Ditmarschen, Husum, Hüll). The systems with two large communicating water reservoirs, instead of those with a single one, seem to be preferable, as they allow an uninterrupted action both day and night, even during neap tide. Their theoretical efficiency, for a difference in sea-level of about three meters, is, however, less than that of a system with a single tank, and is not greater than about 4,800 kilowatts for each sea-tide and for each square kilometer of surface of the reservoirs, and in practice this efficiency is appreciably diminished by a number of uncontrollable factors, as, for example, the irregularities in the level-differences of the tides, to the square of which the energy output is proportional. Such a plant would be extremely expensive and its maintenance would be very costly. Consequently it could economically be operated only under very favorable local conditions. It is therefore probable that no satisfactory solution of the problem of the production of energy in this manner is to be expected.

Recently, however, there seems to be indicated another way of energy production from the sea, which, in my opinion, may become of high significance in the future. I refer to the experiments of G. Claude and P. Boucherot upon the utilization of the relatively small but very constant temperature-differences that exist throughout the year between the sun-heated surface of the tropical oceans and their deeper layers, the temperature of which is kept at from 4° to 5° C. by the cold polar-sea currents. In 1913 your countryman Campbell pointed to the possibility of obtaining mechanical or electrical energy by means of these very constant temperature-differences, and in 1923 Romagnoli, Dornig and Boggia made analogous propositions. It was, however, only recently that the well-known French chemist Claude and his collaborator Boucherot succeeded in giving experimental proof of that possibility. They were able to demonstrate that a small Laval turbine designed to be driven by steam within pressure limits ranging from 20 to 0.2 of an atmosphere, can advantageously be driven by water vapor with tensions between only 0.04 and 0.01 of an atmosphere, corresponding to temperature-differences between 25° and

8° C. only. According to their calculations and experiments, a net output of 54,000 kilogram-meters could be obtained from each cubic meter of water between 28° and 5° C., if there be subtracted the energy that is necessary for pumping the cold and air-free water from the depth of the ocean to its surface. An installation of this kind having a capacity that effects the displacement of 1,000 cubic meters of cold water every second, would be able to produce 400,290 kilowatts of electrical energy, this efficiency being about thirty or thirty-five times as great as that of a low and high tide plant of the same dimensions. In their provisional installation at Ougree-Marihaye, Claude and Boucherot recently demonstrated before a meeting of engineers that a turbine could be run by utilizing the slight temperature-differences of the water of the Meuse, ranging only from 28° to 8° C., and that it could drive a dynamo with a capacity of fifty-nine kilowatts. The calculation by Boucherot of the necessary costs of installation seem undeniably to indicate that the practical realization of this idea lies very probably within the limits of technical possibilities.

The question as to whether it would be possible to use our present stocks of coal and oil in a more economical way than is now usually applied is of high importance and has often been the subject of discussion and investigation. In the present exploitation of our oil fields, about three fourths of the oil remains in the soil. This needs, in the future, to be recovered by some process suitable to the purpose. Even the continuous improvement of the steam engine, or its substitution by turbine or gas motor, can not eliminate the ominous fact that the greater part of the heat of combustion of the coal and oil will, when thus used, always be wasted. At the present time it seems that the most effective way of limiting, as far as possible, this squandering of energy consists in the combustion of the coal *in loco, i.e.,* at the mines themselves, and the immediate utilization of the heat of combustion for the production of high-tension electric currents. It is possible that some way may be found for transforming the potential energy of the coal directly into electrical energy, but experiments along this line have not yet met with practical success. None of the so-called "fuel batteries" constructed for this purpose in the last decade can be considered as being adapted to practical development, because their current efficiency, even at higher temperatures, remains in each case much too small by reason of the unsatisfactory reaction-velocity of the electrochemical processes going on in them.

As the matter now stands, we can say that in answering the question as to how to make the future necessary energy-production most completely independent of the fossil stocks of energy accumulated in former geological periods, we are chiefly confined to the mighty current of radiant energy that is flowing to us directly and continuously from the sun. This quantity of radiant energy appears to be stupendously great, but it is now almost completely lost by dissipation. Some data may give you a clearer understanding of this fact.

According to Langley's measurements of the solar constant, each square meter of the earth's surface receives, every hour, a quantity of radiant energy that is equivalent to 1,800 calories. If we regard the sun as limiting herself to an eight-hour working day in tropical regions, it can be calculated that every square meter of the earth's surface daily receives from the sun's radiation a quantity of energy equivalent to the heat of combustion of 1.3 kilograms of coal. For every square kilometer this is equivalent to 1,300,000 kilograms of coal, which means that the total annual amount of energy produced throughout the world through the combustion of coal would be equaled by the radiant energy of the sun which, during a like period, falls upon a surface of only 3,300 square kilometers (1,275 square miles). The desert of Sahara has a surface of about six million square kilometers (2.3 million square miles), and therefore annually receives a quantity of solar energy that is equivalent to more than 1,800 times that derived from the world's total yearly consumption of coal.

At present this enormous quantity of energy is almost completely lost; only three per cent. of it is absorbed and used by the living plants on the earth. Although this percentage is a very small one, the total quantity of radiant energy annually absorbed in this way over the whole solid surface of the earth still amounts to about fifteen times the yearly world consumption of coal. But the question arises as to whether and in what way it would be possible to catch the enormous quantity of solar energy that now is dissipated every year, and to apply it to the production of mechanical and electrical energy.

In the consideration of this question two points should be emphasized at the outset; first, the necessity of concentrating and accumulating the solar energy supplied to large surfaces; and second, of absorbing this solar energy to the greatest possible extent. Absorption must precede the transformation of radiant energy into those other forms in which it can be used for our immediate purposes. After absorption, the solar energy may be immediately transformed into heat which may then be utilized in the usual manner for the production of mechanical work, or the radiant energy may be absorbed by special substances in which it sets up a "photochemical" reaction and thereby produces a certain amount of chemical energy. This chemical energy can afterwards be changed into another form of energy suitable for our use. Nature has solved the latter problem of utilizing the solar energy through a most remarkable photochemical process in which that mysterious laboratory which we call the "living vegetable cell" is involved. The plant utilizes the radiant energy of the sun to synthesize a large number of complicated chemical substances in its protoplasm. These compounds accumulate in the plant organism, and their stored chemical energy can later be employed for the production of mechanical work. We also know of other photochemical reactions in which a fraction of the absorbed radiant energy is immediately transformed into electrical energy. I will discuss these more fully later on.

Let us first consider the other and simpler case of utilizing the solar energy by first concentrating and absorbing it, and then transforming it into heat.

Concentration of the radiant energy may be effected either by means of large lenses or by a system of mirrors; the absorbent heat-reservoir is placed at the focus. In actual practice, only systems of mirrors have been used. These are mounted on a light frame which permits them to be easily rotated, which is, of course, necessary because they must follow the apparent motion of the sun in the sky. The radiant energy concentrated by these mirrors falls upon a metallic reservoir which is blackened on the outside and which contains some volatile liquid that shows a considerable vapor tension at relatively low temperatures. Ammonia, sulphur dioxide or certain organic liquids of low boiling point are employed. An example of this type of installation is that devised by Schulz, in which, using sulphur dioxide, an output of about 1 H. P. was obtained for each square meter of surface of the absorbent reservoir. At the ostrich farm in Pasadena they have used, and perhaps still are using, a conical aggregate of mirrors of ten meters diameter, in the focal line of which a steam boiler was placed. This developed steam at a pressure of from ten to fifteen atmospheres after only one hour's exposure to the sun, and the device was used for pumping water at the rate of 6,000 liters per minute, and for driving a dynamo.

It may be possible that in dry and tropical climates this method of utilizing solar energy may be successful on a small scale, the cost of the equipment being compensated by the fact that the expense of operation is very low. But under less favorable conditions this device can never be expected to yield a satisfactory solution of the problem because it concentrates the radiant energy that falls on only relatively small surfaces. The proposal of Claude and Boucherot offers much greater promise in this respect because it utilizes the energy that is accumulated over the immense surface of the ocean during long intervals of time.

These considerations lead us to the conviction that the final solution of the problem must be sought rather in the utilization of specific photochemical reactions of the radiant energy. I intentionally use the word specific here because experience has shown us that the action of radiation upon chemical substances is highly exclusive in character. The assimilation of carbon dioxide by plants is a well-known example. The radiation is here absolutely necessary for bringing about this reaction which goes on at ordinary temperatures, the living cell bring able under the influence of sunlight and with the aid of its chlorophyll to synthesize a number of complicated substances which we in the laboratory, in spite of the high development of synthetic chemistry at the present time, are able to produce either not at all or only with great difficulty, even when high temperatures and powerful agents are employed.

We are still dependent, for the production of most of our foods and drugs, upon photochemical processes that proceed under the influence of solar radiation in the plant cells. Although it seems possible, according to the experiments of Ciamician and Ravenna, to influence these processes within certain limits by special external stimuli, we really as yet have little understanding of the true mechanism of these reactions. But the researches of Baly, which have shown that moist carbon dioxide may, in the presence of certain substances such as compounds of cobalt or nickel, be transformed through the influence of ultra-violet light into substances like sugar, have demonstrated that it is possible to produce, in the laboratory, compounds that are formed in the natural processes of the living plant. No one as yet has succeeded in carrying on this photochemical synthesis on a large scale. It offers, however, an alluring prospect because, according to Brown's investigations, if it is assumed that a quantity of solar energy equivalent to five calories will transform one liter of carbon dioxide into sugar, and if only 4 per cent. of solar energy during an eight-hour day is assumed to be photochemically active, it would be possible in this manner to produce 374 pounds of sugar every day by the use of a tank having a surface of only one hundred feet square. This amount of sugar, besides its value as a nutriment, would, if used as a fuel, be equivalent to about 154 pounds of coal. It is extremely doubtful, however, whether this method of utilizing solar energy will ever be brought to practical success.

The remaining possible solution of the problem of utilizing the radiant energy of the sun for the production of mechanical work is the application of reversible photochemical reactions which proceed in such a manner that the absorbed radiant energy may be converted into a usable form such as electrical energy. If the reversibility of such photochemical reactions is nearly quantitative in character, the photosensitive system of substances will then, in respect to solar radiation, play a rôle analogous to that of the lead accumulator in respect to electric energy. We might term such instruments "radiation accumulators"; they would be exposed during the day to the solar radiation which would cause a certain photochemical reaction, and then at night when left in the dark this reaction would reverse, the materials would return to their original condition, and the radiant energy absorbed during the day would be set free and stored up for mechanical uses.

It has long been known that such reversible photochemical processes really exist. For example, if a solution of mercuric chloride and ferrous chloride in water is exposed to light radiation, a reaction takes place in which certain amounts of mercurous chloride and ferric chloride are formed, a chemical equilibrium between the four salts being finally reached. If now this solution is placed in the dark, the substances will revert to their original form, and during this inverse reaction the radiant energy absorbed will be completely set free in the form of electrical energy. It is possible to obtain a tension of 0.17 volt by means of such a photochemical cell; consequently a dozen such cells joined in series will yield the current furnished by an ordinary lead accumulator.

Again, such a photochemical cell can be made by placing two platinum electrodes to an acidulated solution that contains potassium iodide and ferric chloride. When this cell stands in the dark, ferrous chloride and a certain amount of free iodine will be formed, the iodine remaining dissolved in the excess of potassium iodide. On exposing this cell to the action of light, the chemical equilibrium is displaced in the opposite direction, and potassium iodide and ferric chloride are regenerated. As with the previous cell the absorbed radiant energy is set free as electric energy.

Another remarkable example of a phenomenon of this nature is described by Rigollot. Two plates of red copper, each of them superficially covered with a thin layer of cuprous oxide, are placed in a saturated solution of sodium chloride. If now one of these plates is exposed to light radiation and the other is kept in the dark, an electric current passes through the wire that connects the two electrodes. This current continues as long as the exposure lasts. The whole system returns to its original state in the dark. If the other electrode is illuminated, the electric current produced in the circuit flows in the opposite direction.

These various experiments furnish definite proof that it is possible to convert radiant energy into electrical energy by means of reversible photochemical processes.

There is, however, one great drawback to the practical application of such a method, and that is the very low intensity of the electrical current that is produced. The electrical work that can be done, which is a product of the voltage and current intensity, is, therefore, in all cases only extremely small. The explanation lies in the fact that the reversible transformations which take place in these cells are characterized by very small reaction velocities, and consequently the energy that is carried off can not be resupplied by the photochemical reactions with sufficient rapidity. The photochemical effect appears in general to be the strongest in those cases of reversible processes in which the oppositely directed reactions are slowest, and because of this fact, some investigators are inclined to doubt whether the utilization of such radiation accumulators can ever be of practical value. This opinion may, however, prove to be unduly pessimistic. The construction of such cells is wholly a problem of reaction-kinetics. If it should prove possible to devise radiation accumulators or Volta-cells in which reversible and very rapid photochemical changes take place when radiation of such wave-lengths as are contained within the solar spectrum is employed, the problem of using solar radiation as a source of energy might be regarded as definitely solved.

We are, however, still far distant from this goal. Photochemistry is still in its infancy and it has not yet outgrown the stage of mere empirism. It is quite possible, however, that when man's existence becomes seriously menaced because of a shortage of energy, photochemistry will rescue him from his distress.

The protection of mankind from this danger rests chiefly upon the physicist and the chemist, and they must ever be on the alert to find solutions for these intricate problems that involve the very existence of our race.

F. M. JAEGER

ITHACA, N. Y.

A MASTER MUSEUM BUILDER

FREDERIC AUGUSTUS LUCAS, 1852–1929

IN presenting some account of the scientific activities of Frederic Augustus Lucas we seem to be justified in giving him the rather old-fashioned title of nat-