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" THE NATURE AND CHARACTERISTICS OF ENERGY "

" ORGANIC ENERGY AND THE LOW-ENERGY SOCIETY"

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CHAPTER 1

THE NATURE AND CHARACTERISTICS OF ENERGY

The discovery and development of atomic power have led to a rash of speculation about the influence which this new source of energy will have on the future of mankind. The prophets of doom say that it will condemn man to a return to the cave. There is no way scientifically to refute this position-here we can consult only hopes and fears. On the other hand, there are those who see in atomic energy the basis for a brave new world, in which war is impossible and men are freed from the necessity to work. This clain can be tested on the basis of man's past experience.

In peacetime, atomic energy will compete with other sources of energy. In the past man has abandoned one source of energy for another only because of the prospect of overwhelming advantage, and then with reluctance. So to predict where and how atomic energy will influence the future we must know not only its costs and the gains to be made through its use, but also the costs and advantages of the forms of energy now in use. The same kind of speculation as has accompanied the rise of atomic power was associated with the introduction of new energy sources in the past, but in the past we did not have the store of scientific knowledge that we have today. This work is an effort to bring together and examine some of this knowledge so that we may increase our ability to forsee the future effects of energy, and to avoid some of the pitfalls into which we might otherwise stumble.

THE PROBLEM STATED

The thesis of the book is simple. It is that the energy available to man limits what he can do and influences what he will do. It will not be easy to establish, for the energy converters man uses are embedded in a social matrix in which it is difficult to distinguish the relationships primarily connected with technical operations from those primarily of social origin. Nevertheless the effort must be undertaken, because only if we can separate the effects of the two types of controlling factor can we know how much of what men strive to do is possible of achievement.

Conflict between communism and social organization in the patterns found in the Free World shapes our day. Free enterprisers hold that the political and economic ideas developed largely in the British Commonwealth, the United States, and Northwest Europe have demonstrated their capacity to deal with industrial society. Communists, on the other hand, believe that only through use of the Marxian model can man fully realize the potentialities of modern technology. Each school holds that if its system is adopted, eventually all the world will share a standard of material well-being equal or superior to that now enjoyed in the wealthier states. Each is expected by its proponents to bring into being a society largely free from toil and poverty, without reference to the geographic and demographic facts or the technological propositions faced by a particular people. Now if the thesis here presented is substantiated, it will be up to these ideologists to show how the systems they propose will convert and distribute energy so that man everywhere will do what they hold he will be able to do, and also to prove that nothing involved in the process of producing and using more energy is likely to influence men to distribute it unequally - or, more specifically, to deny to great areas of the world the wealth it would be possible for them to have if energy were "properly" distributed.

Thus the thesis offered here is likely to raise questions about the reliability of certain propositions which are basic to the policies of both the Communist and the Free World. Some of the makers of these policies will be unwilling to accept its implications. In anticipation of such resistance, our argument has been built upon widely accepted principles of natural science rather than "self-evident" truths about human nature.

The scientist's contribution can be summed up in the formula: If you do thus and so, this will follow. In other words, science prescribes the conditions necessary to bring about change and predicts its consequences. Whether or not human beings can be influenced deliberately to perform or to eschew certain acts in order to achieve or to avoid predicted consequences cannot be learned from the scientific position itself. If we are to predict whether or not a given group will wish to change in the manner required to make use of new fuels and converters, we shall have to know what, in the particular situation envisaged, has to be changed so that these fuels and converters can be used. This means that a careful effort must be made to distinguish between the social relationships that are dependent upon the use of present converters and those that may be expected to continue even though new sources of power energize them. Only to the degree that we know what must be changed can we know the costs of change and so estimate man's willingness to alter his society.

There are and have been many kinds of labels used in explaining why man persists in or modifies his behavior. He has been variously classified as primarily a power-seeking or political animal, a money-seeking or economic being, a being endowed by blood and soil with racial instincts which guide his choices, the helpless puppet of physical or biological forces which move him, an anarchistic element in time and space guided only by his will, and many other kinds of creature. The makers of these labels, having endowed man with a basic nature, then proceed to infer how such a creature should act and predict how in fact he will act. Here we provide no such grand scheme. We are trying to discover the relations between the energy converters and fuel men use and the kinds of societies they build.

The methods involved in trying to arrive at the truth in regard to these relationships are varied. The physical and biological sciences can tell us the nature and amount of energy that can be secured from a given fuel or converter. Examining this evidence enables us to form an idea of the way man would act if limited by this particular source of energy. We can also estimate how he might act if he were to seek to make the most efficient possible use of this source.

Turning from this idea, we shall examine historic evidence to see how in fact people confined to the use of given energy sources have acted. This will indicate the degree to which their behavior has corresponded with that required ideally to exploit their energy sources.

Changes in values and social structure which have accompanied alteration in energy sources will also be examined, along with evidence as to whether or not such changes reveal a common pattern. Analysis of this evidence will provide a means of finding out why some people did not take advantage of known sources of energy by some standards clearly superior to sources they did use.

We make no priori assumption as to the part that energy plays in man's behavior. We shall make an effort to discover what part it does play, in the belief that by so doing we can help to bring about a closer correspondence between the expectations of men and what is likely to happen.

Even the most elementary knowledge of physiology and of thermodynamics makes it clear that man can exist only where he is able to replace the energy which he uses up in the process of living. He must regularly be in control of energy equal to or in excess of this minimum. A permanent deficit makes life impossible.

Beyond this biologically set minimum the amount of energy required by man is set by the goals he seeks. There are few, if any, societies in which men choose to exert no more energy than is required to maintain a supply of food, protection from the elements, and procreation. Rather, there is a wide range of values which induce man to strive for a large number of goals requiring for their achievement control over varying forms and amounts of energy. The preservation of a system of values requieres a continuous supply of energy equal to the demands imposed by that system of values. Conversely, as we shall later show, changes in the amount or form of energy available give rise to conditions likely to result in changes in values, for men who share common values make similar changes in choice when faced with similar changes in the consequences of their acts. These changes in choice are influenced not only by the values they have learned but by changed limits as to what it is physically possible for them to do. Thus the possibility of predicting change depends as much on a knowledge of the physical potentialities in a situation as it does on a knowledge of the values men hold.

Probably as a result of the errors of the physical determinists and the Marxists, there has in the United States particularly been a marked hesitancy to examine the social consequences of the physical arrangements by which men live. There have however, been a number of fruitful investigations. Among the social scientists, W. F. Ogburn, Lewis Mumford, George K. Zipf, John Q.

Stewart, Leslie White, Hornell Hart, and numerous others have given particular attention to the social implications of technology and of the energy it makes available. This book starts with a somewhat different type of investigation from theirs and arrives at somewhat different conclusions, and no attempt will be made generally to discuss their contributions.

The approach here used cuts across many of the traditional lines of division of labor among social scientists. This gives rise to some of the same kinds of difficulties as have confronted other scientists using energy as a common denominator. Many things which are elementary to the specialist in one field must be said for the sake of the reader who is not trained in that field. Thus readers sophisticated in any of the areas covered will find the work a mixture of elementary and more advanced levels. This difficulty may be illustrated by the concept of energy.

ENERGY DEFINED

Energy must be defined in terms of the ways in which it manifests itself. It is variously classified as heat, light, sound, radio, radar, TV, electricity, magnetism, mechanical energy, growth, and even "matter". At one time it was difficult for the layman to accept the fact that these fields represent different manifestations of the same thing, and even today in the face of "the bomb" and of the everyday miracle by which electricity is converted in the average household into many other forms of energy, conversion of energy from one form to another is not yet a commonplace. To do justice to the concept of energy would require treating each of its manifestations as it is treated by experts in that particular field. We must ignore the somewhat variant meaning of the concept to experts in various scientific pursuits; a common core of meaning as shared by layman and expert is the most that we can deal with in these pages.

Energy Converters

It is apparent that, as a means to convert energy, man can be measured like any other converter. This is not to say that in every situation the most significant thing about a man is that he is a converter — even though when he ceases so to be he is dead. It is to say that, significant or not, it is a fact that if man acts, his activities can be measured in physical terms.

Man also makes use of converters other than his own body to achieve his ends, and the energy these converters make available to him is also measureable. Thus wherever other converters can be used to replace or supplement the energies of man, the relative advantage, in energy terms, of using them over using his own physical effort can be calculated. However, such calculations will not alone serve to indicate whether the more or the less efficient converter as so measured will, in fact, be used. One of the problems incidental to this study will be to discover some of the conditions under which man will be likely to continue to pursue a course demonstrably "wasteful" of energy in preference to a more efficient way. Man seems frequently to follow such a course. For this reason we do not here accept Zipf's[1] conclusion that inevitably man will "in the long run" modify his culture in the direction of making life physically less difficult. In fact, there are some very old practices which are deliberately continued in use as if in response to an urge to do things "the hard way".

[1] See References cited by chapter in full at the end of this book.

MEASUREMENTS OF ENERGY

To calculate the costs and gains of any action requires the use of common measures and accepted concepts. For convenience some of those frequently used in this book are presented in this chapter. Newtonian physics assumes that material objects will keep their existing relationships unless acted upon by an outside force. In other words, work is defined as a factor responsible for some sort of change in physical relationships. This may be a change of form, time, or place. Energy, in turn, since it is defined as the ability to do work, is involved in any change in physical relationship. A good deal of the time we shall be dealing with the potential energy to be derived from a change in a given source of energy. Such energy as is actually involved in doing work is called kinetic energy. Kinetic energy takes many forms, each of which can be measured. For example, mechanical energy is measured by setting up an arbitrary unit to measure force and another to measure distance. These two measurements are multiplied to give a composite figure. So, for example, a force adequate to lift one pound a distance of one foot is a foot-pound; that capable of lifting one kilogram a distance of one meter is a kilogram-meter; etc. These measurements have in turn been converted into other convenient units. Thus when Watt was attempting to sell his steam engines he found it necessary to state the relative capacity of his engine as compared with that of the horse, which the engine was often expected to replace. Watt set out to determine the strength of his engines as compared with that of the horses then in use in England. By testing them he discovered that the average horse could do 22,000 foot-pounds of work per minute for as long as 10 hours a day. In fixing on a unit to state the power of the steam engine, he arbitrarily increased the figure based on the horse by one-half, to ensure that the purchasers of his engines would get full measure, making the horsepower equal to a rate of 33,000 foot-pounds of work per minute, or 550 foot-pounds per second. This measure came into wide use with the adoption of the steam engine.

It may be well to state here the equivalence of some measures of heat and mechanical power that will be used. One kilowatt-hour is equivalent to 1.34 horespower-hours and to 860 Calories; 1 horsepower-hour equals about 641.56 Calories. (Technically the great calorie, or the kilogram-calorie, this is the unit in which diets are commonly stated; it will be referred to throughout simply as the Calorie.)

Acceleration

It was stated above that mechanical energy is calculated in terms of motion, force and distance being used as parameters. However, force itself was arbitrarily described in terms of pounds, a measure commonly used to express weight. To measure force in motion we must add a new dimension. This is acceleration, the rate of change of speed of movement. The specific relationship between rate of motion and energy required to produce it has been established empirically: the energy is equal to one-half the mass times the velocity squared. If the mass remains unchanged, it is clear that to increase the rate of motion of an object requires energy in proportion to the square of the velocity. Thus, at high speed fairly large increments of energy may have only slight effects in altering the rate of motion.

Another of the laws of physics with which we shall be concerned is the principle of the conservation of energy. Newtonian physics hold that the amount of energy in the universe is a constant, and thus energy is never lost or gained. Man never creates energy or destroys it. These words have meaning only in terms of human values. What we mean when we say man creates energy is that he increases its supply at the time and place and in the form in which he needs it. He consumes energy when he makes it less available to serve his purposes. The efficiency of a converter is a measure of the proportion of the energy fed into it which is converted into the form desired. It is not only a physical measurement; it is also a social estimate. For example, blood sugar is converted into various forms of energy by the human body. Winter or summer, muscular exertion requires chemical change in that sugar, which also results in the giving off of heat. In winter the heat is often desirable, and exercise may be indulged in for the simple purpose of warming the body, whereas in summer the heat is frequently an undesired concomitant of exercise and its reduction would be welcome. Thus the efficiency of the body in converting food into energy would vary from season to season with the change in the ends desired. Usually the engineer simply assumes the social objective of the system in which he is working and measures in terms of it without further concern. If he is designing a light bulb he seeks to minimize heat; in a heating element he reduces to the lowest possible point the proportion of light rays being generated. But without a knowledge of the forms of energy being sought he has no means of determining efficiency.

THE ENERGY FIELD

There are a number of other concepts with which we shall have to work. The thesis that the energy available to man determines what man can do means that energy sets a limit. The idea that energy influences what man will do implies that within the limits to set the supply of energy is also a factor at work influencing choice. This kind of situation involves what is termed a limited field. The concept of limit is one very familiar to us.

As applied to the discovery and measurement of energy, it is the point at which the energy being discovered ceased to have an effect upon the instrument used to discover and measure it. A Geiger counter shows the presence of radioactive substances; when it ceases to manifest any change in the presence of a substance we say we are outside the field of any radioactive substance, or beyond the limits of such a field. A battery yields a flow of electricity; when it ceases to affect an instrument designed to reveal a flow of current, we say that so far as the instrument is concerned the battery no longer creates a field, that the instrument is beyond the limits of the initial supply of energy the battery was capable of generating. If a thermometer placed in or near a furnace shows no perceptible change from the temperature which it exhibited at a more distant point, we say that the fuel which the furnace contained has been exhausted or the fire extinguished. Perhaps nothing more need be said about this familiar aspect of the concept, which relates to the total amount of energy. However, there is often another type of limit involved: the rate at which a converter can change energy. Enlarging the gas tank will not make a car go faster. A man who can easily lift a thousand bricks one at a time may find himself totally incapable of lifting all of them at once. Obviously the factor limiting the rate of conversion are other than those controlling the total amount of energy yielded. Since we are so frequently confronted with limits — on the amount we can lift at one time, on the speed at which we can run, on the amount of light yielded by a bulb, on the distance we can go in a given time in a car — this form of limit needs no further amplification.

The concept of the field, already in part described, is a little more difficult. The field is the sphere of an operation, that is, it is the range within which what is being observed retains its identity and affects an instrument in a manner significant to the observer. Fields are often recognized as a consequence of the pattern which they reveal. If a stone is dropped into still water, concentric circles spread across the surface; revealing the way the energy derived from the falling stone is being dispersed in the water. Most of us have seen how iron filings, sprinkled on a sheet of paper spread over a magnet, reveal the magnetic lines of force which constitute the field of the magnet. The converters which man uses have similar patterns. To use them most efficiently requires variation — in the way farms, roads, and streets are laid out, buildings are erected, and other structures are placed. The shape of the pattern existing in a man-made structure demonstrates whether or not it was constructed in such a way as to use a given converter efficiently. Such patterns give some evidence of past effects of the use of energy. Ecological study of man thus provides a means of showing what values have been operative in the past and also of indicating to a certain extent the changes which will be required if new converters with different fields come into operation.

CONVERSION RATE OR GRADIENT

Aside from this type of concept which deals with structure and form, we need a concept which will deal with the dynamics involved, that is, something to make it possible for us to measure the rate of conversion in one situation as compared with that in another. The rate of conversion can be expressed in terms of time or of distance. It can also be expressed as a fraction of the initial supply of available energy, a quantity of fuel consumed in a specific period of time or distance, or in some other manner. This is usually done by setting up a pair of coordinates, measuring on one axis some attribute such as the energy available and on the other time or distance, thus showing graphically how the two factors are related. For example, a graph may be set up showing, on one axis, the total gasoline in an automobile tank in terms of gallon units and, on the other, distance in terms of miles. Such a graph may be used to demonstrate the difference between two cars as to gasoline consumption. One of the coordinates might represent time rather than distance, in which case the graph would show how fast the consumption of the gasoline was taking place, or perhaps the difference in gasoline consumption of the same car at different speeds. The graph may be constructed from a known rate of consumption or may represent empirical observations (actual distance traveled and actual quantity of gas in the tank). Such graphs are very familiar. Commonly they are so constructed that the slope of the line joining the coordinate points becomes a significant indicator of the facts which are being portrayed, and a calculation of that slope can be made in terms of a mathematical equation. Since the slope of the line resembles an inclined plane, or what we call when we are climbing, a hill a "grade", many sciences use the word gradient to indicate this relationship. Usually a rapid rate of consumption of energy is represented by a steep grade and a slower rate by a gentler grade.

A single line serves to show the particular gradient of a specific operation, but to represent the potential effects of an action, or the range of possible actions, another kind of representation is necessary. If, let us say, our automobile was in the middle of a perfectly flat plane (for example, the Utah salt flats), so that it could equally well move in all directions, in order to show all of its potential movement (assuming in each case that the path taken would be a straight line), we would have to revolve our single line, marked off into segments showing the rate of energy use, about the point of departure. We would thus generate a series of concentric circles. To show high energy consumption we would construct one set of circles close together, and to show a field with gentler gradient we would draw the circles farther apart. The outermost circle would represent the point of exhaustion of our original supply of energy, and the others would show the proportion of energy which would be consumed by the car in reaching that series of points represented by a particular circle. So we could visualize the whole potential field. As we shall see, the comparison of the gradients and the fields of different converters gives us a means of discovering the degree to which actual behavior conforms to optimum behavior in energy terms.

SURPLUS ENERGY

There is one other general concept used throughout the work which should be defined here — the concept of surplus energy (often shortened to surplus). This is the energy available to man in excess of that expended to make energy available. Like the concept "efficiency", surplus energy represents a social estimate of a physical fact. Like efficiency, it has sometimes been a source of error because it has been taken to be exclusively a physical fact rather than a concept involving the process of valuation. To be sure that there will be no question as to what is meant by the term, we shall elaborate on our definition. At any given moment of time a man, a group, or any other socially functioning unit has available a limited supply of energy. This can be utilized immediately in its present form. It can also be used in an operation designed to increase the future supply of available energy. The simplest example would be seed grain, which may be eaten or planted. It is obvious that if the planter does not even get his seed back from the harvest, he has less energy at his disposal than he previously had: he has incurred a deficit.

On the other hand, if he harvest enough grain to replace the seed, to supply the amount of energy expended in planting, cultivating, and harvesting his crop, and to get something more, he has gained energy beyond that which was previously his to command: he has surplus energy. A stroller eating blackberries growing wild along the road expends in the operations necessary to secure the berries only a small part of the energy he receives from them. He has gained surplus energy. On the other hand, a man who runs down a jack rabbit in an 80-acre field will probably expend more energy than he will gain from the operation.

In the more complex activities of modern society it is sometimes extremely difficult to discover all the costs and all the gains, energywise, which are involved; yet it is clear that the same propositions about energy hold for complex actions as hold for the simplest examples given above. The continual undertaking of projects that produce less energy than they consume inevitably leads to a deficit, and this must be made up from other operations in which there is a surplus if the society is not to find itself with less energy than it had before the projects in question were begun. As will be shown, in the older societies deficits were rather quickly detected. Either steps designed to correct energy deficits were taken quickly or the culture soon disintegrated. In more modern societies the facts are extremely difficult to come by. The struggle to determine the point where output exceeds input, or to assure that surplus energy from some operations can be depended upon to supply the deficits from others, is inconclusive and is usually prolonged until some crisis forces recognition of the deficit or results in collapse of the system.

It is assumed here that the value of energy in the situation in which it is being expended to create new energy is unchanged when, in turn, surplus energy becomes available, and hence the quantities of energy can be compared. In other words, the assumption is that there is no qualitative change in energy input and output. For example, it is assumed that energy in the form of seed can be treated as being, energywise, the same commodity as results from the harvest — or, again, that kilowatts of electricity going into the mining of coal are comparable to kilowatts of electricity manufactured by means of the mined coal. We here treat energy as being so easily converted from one form to another that it can for some purposes of calculation be considered neutral as a commodity and therefore capable of treatment on a strictly quantitative basis. The inconvertibility of other fuels into food makes a significant exception to this proposition, and we shall later have to deal with that difference at length. Throughout our discussion we must keep clear the distinction between the operations that produce surplus energy, and determine its amount and form, and those that determine the social claim placed upon it.

Some economists have attempted to deal with the problem of surplus energy on the basis of moral and religious propositions derived from man's experience of an earlier day. The fact is that the struggle to create morals which will furnish a rationale for the disposition of surplus energy is probably one of the crucial points of conflict in modern society. It is obvious that since the amount of surplus is clearly related to the social system under which it is being produced the two activities are not entirely separable, but it is possible to measure the first of these sets of facts with tools that are not dependent for their reliability upon assumptions peculiar to the situation in which they are being used. The possibility of doing this represents a real advantage.

To recapitulate, we shall be constantly using concepts and measurements taken from various sciences. They will be used with exactly the same denotations that they carry in these sciences. It is hoped that certain new connotations of some of them as they relate to social phenomena will be seen to be necessary attributes of their use in real situations. Among the concepts are those of kinetic and potential energy; field, limit and gradient; and such measures as the Calorie, the kilowatt and the kilowatt-hour, the horsepower and the horsepower-hour. We shall assume a knowledge of the concepts of mass, acceleration, distance, and the energy relationships that exist between them, of the law of the conservation of energy, and of the concepts of efficiency and surplus energy. If they are kept clearly in mind and reexamined from time to time, it will add to the book's readability and serve to keep the reader on his guard against the errors that inevitably creep into a work of this kind.

Other concepts, particularly some from social science, will be brought in as needed. It seemed advisable to define them as we go along, in the context in which they are used, rather than to introduce them here.

CHAPTER II

ORGANIC ENERGY AND THE LOW-ENERGY SOCIETY

With only insignificant exceptions, such as the limited amount of energy available on earth from lunar gravitation and from cosmic rays, the energy that is available to man has come, or currently comes, from the sun. Uranium and other possible sources of atomic energy were created as the gases from which the earth was derived combined to form solids. Coal and oil, peat and gas are accumulations stored in the earth's crust from past operations of plant and animal life that have converted the radiant energy of the sun into energy-laden substances. We shall treat these resources as if they were of a different type from those that make use of the recurring presence of the sun. While they represent only a tiny accretion as compared with their original source, they currently provide man with his major sources of energy. This is primarily due to the fact that one of the still unsolved problems of science is how to take full advantage of the sun's energy.

It is obvious that it is not lack of a source of energy which limits man's activities. The amount of sunlight falling upon the earth's surface is so great that it is almost incomprehensible.[1] An acre receives about 20 million Calories per day, and the amount of solar heat that falls on only 1½ square miles in a day is equivalent to that generated by an atom bomb such as that used at Hiroshima. Thus the amount of radiant energy is so far in excess of man's present ability to convert it that it cannot be considered to limit human behavior. Energy-imposed limits stem from the particular means by which energy is converted into the particular forms desired by man at a particular time and place.

PLANT AS CONVERTERS

Man has learned to convert radiant energy into other forms in only tiny amounts at a relatively high cost.[2] He has depended upon the action of plants to make the original synthesis and has proceeded from there to convert the resultant energy for his own purposes. His simplest method has been to eat plants, thus making some of their energy available to him. This system requires only a knowledge of what is edible. The converters automatically divert energy in sufficient quantities to ensure their own reproduction. This plant-man system is the prototype of all the systems of converters man uses; however, since man very early undoubtedly also ate animals, the plant-animal-man system is not much newer.

Plants vary in their capacity to survive in various soils and climates, and we can through the study of plant and animal ecology discover the limits within which the survival of various plants is possible. Plants also vary in their capacity to convert the energy of the sun into plant structure; Willcox[3] has shown that "the fixation of the calorific energy of the sun is variable with the species". The limits of the use of radiant energy by plants are fixed by the nature of photosynthesis itself.[4] It has been well established that only a small fraction of sunlight can ever be converted into other forms of energy by plant life. For example, it is estimated that only about 3-1/3 per cent of the sunlight falling on the United States as a whole could be so converted. As a matter of fact, no crop grown in this country even approaches such a figure. Here corn is the crop that probably yields the largest heat-energy return, and a bumper corn crop returns only about 0.3 per cent of the radiant energy falling upon the land on which it is grown. This return includes the heat which can be obtained by using the cobs, stalks, and leaves as well as the edible kernels. Such a return is exceptional. "Corn belt" corn is the product of extremely favorable geographic conditions, aided by scientific agriculture. In areas where the land is poorer and farming practices are less efficient the returns are very much smaller.

The amount of energy each plant can convert is specific to that plant. Willcox[5] gives the simple formula worked out by acrobiologic science for ascertaining what it is: "Divide 318 by the normal percentage nitrogen content of what every agrotype is being considered; the quotient is the theoretical absolute maximum number of pounds of every vegetable substance which that agrotype can yield on one acre of ground in one crop cycle." Now since a plant also consistently yields a given quantity of energy per pound of dry weight, it is possible to discover the limits that are self-imposed on a people who choose a given crop as their basic diet. Rice apparently comes closest to yielding the various food elements in the proportion required by the human body; but Indian corn, soya beans, millet, rye, and wheat have become the basic diet in some areas, as have potatoes, sweet potatoes, and other crops in other areas. The particular crop which would provide the largest energy return in a given area is not necessarily the one used there. Factors other than energy efficiency affect the choice of foods made by man, and in a given instance the preference may be for a food that is less efficient than some other known and available food source. The total energy available to the people of a given area is thus determined by the inherent efficiency of the particular plant they have chosen to make their source of food.

Plants have in addition to their inherent efficiency another characteristic of great social significance. With few exceptions they are rooted in one place; thus the field in which a plant can act as a converter is the area which the plant itself occupies. Concentration of the energy which they produce involves the energy costs of harvesting them. Moreover, any mechanical energy which is derived from using them must involve another converter.

Where the only converters available consist of plants, animals used solely for food, and man, not only is man the controller and director of available energy, but his muscles provide all the mechanical energy he commands. And all operations which require the use of mechanical energy are limited to such as can be carried out by human beings.

Although man is a chemical-energy machine, his efficiency can be measured in terms of the heat value of the food he consumes as contrasted with the heat value of the mechanical energy he can deliver. Part of what a man consumes is utilized in such functions as respiration and the circulation of the blood. Part is given off as heat, and part is indigestible and leaves the body as waste product. Some energy is lost during sleep, and some is converted in the activity of the nervous system. So, as in the case of other engines, the total heat value of the fuel consumed can never be recovered in the form of mechanical energy. The average efficiency of the human being is about 20 per cent. This means that for each 100 Calories consumed as food the average man can deliver mechanical energy equivalent to 20 Calories of heat.

Physiologists are generally agreed that to maintain efficiency the average daily consumption of food should not be less than about 2,600 Calories per person per day. It is improbable that any population with a normal number of children and old people in it could consume more than 3,000 Calories per day per capita without producing excessive fat, which actually reduces the capacity to work. Three thousand Calories average intake and 20 per cent average efficiency provide mechanical energy equivalent to 600 Calories per person per day. This is a little less than one horsepower-hour (about 641.56 Calories).

No society keeps its members steadily employed at converting food into economically productive mechanical energy, and many societies have never supplied their members with as much as 3,000 Calories per day. Thus in many societies there is available considerably less than 1 horespower-hour per day of mechanical energy per capita. Part of this mechanical energy must be used to produce or gather food. The remainder may be used for other pursuits. But no matter how little is used in procuring food the sum of the two cannot exceed the very modest total set by man's capacity as a mechanical-energy converter. Thus, regardless of the food supply, the difference per capita between the most and the least fortunate of societies, both using only men as mechanical energy converters, is not very great. The average consumption cannot fall very much below 2,000 Calories per day per person and, as we have seen, it cannot rise much above 3,000 Calories. So even taking the maximum difference in food consumption between the lowest and the highest to be as much as 1,000 Calories, at an efficiency of 20 per cent there is a difference in total mechanical energy available equivalent to about 1/3 horsepower-hour per day per person. Nor is this fact significantly affected by the use of animals rather than, or in addition to, plants for food.

ANIMALS AS CONVERTERS

The differences between those who consume plants only and those who make use of animals as well as plants for food are probably significant rather for the pattern than for the limits of the field generated. Man usually adds meat to his diet if he can, and under some circumstances his chances for survival may be tremendously affected by his ability and willingness to provide himself with animal food. The chief significance of the use of animals lies in the fact that some edible animals can assimilate plants — and parts of plants, such as bark — which man cannot directly digest. Many of the grasses which are not directly consumable grow in areas where it is not possible for man unaided by other sources of energy to replace them with edible plants. Since sheep, goats, and cattle on the hoof can be driven over distances much greater than it is possible for a man to carry or drag the meat of their carcasses, man is able by following or driving livestock to consume the plant products of an area enormously more extensive than he could otherwise make use of. Similarly, man is able to live in climates where plants are not available the year round, partly by using the energy of plants stored in the form of animal products during the months when no plant food is available. Occasionally even carnivores are used to promote man's survival. The Plains Indians sometimes lived through a hard winter by eating the dogs which had shared their kill during the summer months.

The use of animals for food is subject to the limitation that the animals so used are in competition with men for plants. The number of plants in an area sets the limit on the food available both for man and for other animals. If man permits animals to eat plants which he otherwise might himself eat, or permits land to be used to raise plants for feed which could be used to raise plants for human food, he limits the number of men who can be fed from that land. Wheat, which is very widely used as a foodstuff, will serve as an illustration of this relationship. The amounts of energy made available to man through the use of wheat in the form of bread and in the form of animal products are shown in the table on this page.

Since other feed crops can usually be grown more advantageously, wheat is only rarely raised to feed animals. However, other plants edible by human beings exhibit the same pattern of loss as does wheat. Man gains through eating animals only a fraction of the energy contained in the plants eaten by those animals.

100 LB OF WHEAT CONSUMED AS	YIELD IN CALORIES
Bread	120,000
Chicken	9,625
Eggs	30,000
Pork	38,700
Milk	25,230
Beef	11,500

Nevertheless, in many areas people permit animals to survive even though this results in reducing the number of human beings who can live there. The case of the sacred cattle of India, which are permitted to eat food which would lengthen the life span of a large part of the population, is an example. Elsewhere animals are kept for the enjoyment of a particular class, as were the deer of the English forests. Sometimes, too, an inefficient use of animals is required by religious belief, as in the case of the Jews and the Mohammedans, who are prohibited from eating the flesh of swine, which happen to be more efficient converters of plants than are cattle. But in certain large areas such as China, in some parts of Eastern Europe, and in Southeast Asia, men are unable to eat meat simply because the plants which animals might consume go directly to human consumption. In these areas a return to the consumption of meat could come about only with widespread reduction of the population or enormous increase in the available plant food supply, or both. In 1940 about 55 per cent of the world's population had a daily intake of 2,000 Calories or less; 30 per cent had 3,000 or more, and 15 per cent had about 2,500. The world average was about 2,400 Calories per day.[6] Asia, where the population presses most closely on the food supply, produces about 49 per cent of the plant foods but only about 16 per cent of the meat, dairy, and poultry products. With the world's population increasing steadily, it is unlikely that in most areas there will be any large general increase in the use of animals for food.

The domestication of draft aninals greatly increases the mechanical energy available to those who possess them. There are many varieties of animals used for draft, and in order to be exact it would be necessary to calculate the costs and output of each kind. However, since the horse is so widely used it will serve to illustrate the energy gains to be made through the use of draft animals. As we have already indicated, Watt found that the horses in use in England in his day produced the energy equivalent to about 2/3 horsepower, or about 6 horsepower-hours per 9-hour day. Morrison[7] says that a modern horse weighing 1,500 to 1,600 pounds can convert about 1 horsepower steadily for 10 hours a day, and that the average horse is about 20 to 25 per cent efficient. However, since horses in the United States today work only 800 to 1,000 hours a year, they deliver only 6 to 7 per cent of the heat value of their average annual food consumption. A man working 50 hours a week for 50 weeks a year delivers, then, only ¼ as much energy as a horse, but the heat energy consumed by the horse is 10 times as great as that consumed by man. Compared strictly on the basis of energy, under these conditions man is $2\frac{1}{2}$ times as efficient as the horse.

The great value of the horse lies in the rate at which it is able to deliver energy. During a limited plowing season, for example, a man and a team can prepare a very much larger area for planting than can a man alone. Outside the tropics only a limited number of days can be spent in preparing the seedbed and planting. Crops require a minimum growing season and the interval from the time when the ground can be worked to the time when frost sets in. Where the limit on the size of the crop that can be raised is found in the length of the period during which land can be prepared, the horse, by permitting a great increase in the amount of land plowed, may more than compensate for the days when it is idle.

It must not be forgotten, however, that the efficient use of draft animals takes place within distinct limits. In the first place, arable land is not always available in such quantities that plowing or harvesting is the limiting factor on the crop raised. Frequently the number of persons who have a right to share in the product of the land is great enough to make it possible for them to plant and harvest all the available land in time permitted by the growing season. In such cases the net cost of using the horse would be greater than the increase in the energy returned. Furthermore, in many cases land that cannot be cultivated by the use of the horse exists interspersed with land fit for horse cultivation and land fit only for pasture. Where this is so, an economy that made use of the hoe could support a larger population than could an economy that used only such land as could be cultivated by horses.

Because man's skill, intelligence, and dexterity enable him to do many things not possible to a horse, man can be employed many more hours of the year than the horse can. His efficiency rises proportionately. Thus those who control the method of cultivation may choose to rid themselves of horses in order to employ men. This might take place in an area dominated by the family as an economic unit because it would obligate family members to work for the food they had a right to share anyway. In a feudal or slave system the value of men as a source of military power and prestige or as contributors to the bodily comfort of the landlord or slave-owner often resulted in the displacement of horses by men. Where other values and social structures prevail, the relative efficiency of men as compared with draft animals in securing the desired results has determined the choice as to which would be permitted to survive.

One of the early evidences of population pressure is the reduction in the number of food animals, followed by the reduction of draft-and-food animals, such as cows and horses, in favor of those draft animals, such as the water buffalo, which can survive on the plant product of land which will not yield nearly as much energy in the form of humanly edible food. Thus many areas which once supported draft animals and food animals now make use of almost none. This tendency to regress has frequently been checked. The failure of a society to utilize its land in such a way that the land provides sufficient energy in the requisite form to maintain the population has often resulted in the society's being overrun by outsiders. If a society uses its land in such a way that it passes the point of diminishing energy returns, it may be conquered by a neighbor with greater surplus, who then may ruthlessly restor that land-to-population ratio which will yield maximum surplus. Feudal landlords who permitted the population to grow to the point where they had no horses were often defeated in battle by their horse-riding neighbors. The exploits in India and China of such horse-riding herders as Genghis Khan give evidence of some of the dangers of overpopulation.

The difference between the maximum and minimum mechanical-energy surplus available to those using only plant and animal converters is by modern standards very small. But in the absence of other energy sources these differences have been very significant.

Today all but the more primitive societies supplement plants and animals with other sources of energy; and it is therefore necessary to turn to the data on such primitive societies provided by anthropologists, archaeologists, and historians to ascertain the relation between plant and animal use and social life. These data have not, however, been presented in terms of the analytical concepts used here, and ideally they should be reexamined in terms of these concepts. Practical considerations preclude our doing this, and what follows is based upon summaries of anthropological and other research into primitive peoples. The result is the use of analytical categories that are not entirely germane to the problems here under consideration, but no better alternative is at present available.

FOOD-GATHERING SOCIETIES

One method of classifying societies is that developed by Forde in his classic work *Habitat, Economy and Society*. He groups the societies he discusses in three categories: food gatherers, cultivators, and pastoral nomads. We have found it expedient to lump the two latter types under one heading, "food raisers". The data that Forde worked with were collected by men using various field categories that could conveniently be subsumed under his types. All the societies studied are primarily dependent upon the use of plants, men, and animals as converters. The differences that they exhibit give some evidence of the range of social relationships possible within the limits imposed by these energy sources; they also give evidence of the social consequences of even slight variations, by today's standards, in sources and amounts of available energy.

As Forde points out, food gatherers are for the most part without the accouterments of "civilized" man. The surplus energy gained under this system is very small on an annual basis, though it might temporarily be enormous during berry-picking time or the salmon run or after a buffalo hunt. The total energy annually available does not permit any great expansion of population, and thus food gatherers have frequently fallen victim to the more numerous and powerful food raisers. In point of fact, once domestication of plants and animals has developed, the food gatherer has tended to be driven away from the areas in which food raising was possible. As a result, he currently exists chiefly where food gathering actually yields a higher return from existing resources than would an available alternative land use. The precarious existence of such contemporary food gatherers as the Eskimo, the Athabascan hunter, and the Indians of the Orinoco suggests why food gatherers often fail to survive in the face of more effective systems of energy exploitation.

Since food rarely grows in such abundance that a group can long remain in one place, everything that food gatherers use must be transported. Their means of transportation are, characteristically, limited to human portage or sledge dogs. Consequently, tools must be simple and light in weight. Housing must either be improvised at many different sites or be very easily transportable. Clothing must be light and simple. No great energy can be devoted to the erection of shrines or otherwise expended in placating or worshiping the gods. The size of the social unit is necessarily small, for if any great number of people gather together, they soon exhaust the local supply of most of their energy sources and have to range far afield in the search for new sources. The resulting expenditure of time and energy in gathering and dispersing endangers rather than contributes to survival. At best the division of labor is limited, for almost everyone must spend a great deal of time and energy in the pursuit of food. Priests and other social functionaries who gather no food cannot contribute enough to food-gathering groups to offset the energy lost in supporting them. The kinship groups among food gatherers may carry on economic, political, and religious functions, but such small units are incapable of creating or transmitting any very large culture base; consequently tradition, law, and religion remain relatively simple,* providing only a limited number of controls for the guidance of the head of the household.

The Paiute of the American West provides an example of the social simplicity of the life of the food gatherer. He lived principally upon a few types of seeds, such as the pine nut and acorn, upon lizards and snakes, grasshoppers and grubs, and the rabbits and the rare deer which he could kill. To get the latter, as Forde[8] puts it, "the deer hunter usually went out

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* Simple, that is, if the culture as a whole is compared with that of the large social units of urban society. Some single aspect, such as the kinship system itself, may be relatively complex, as in the case of the aborigines of Australia.

alone with his dog. Finding his quarry, he then had to run it down relentlessly, perhaps for several days, until he could get close enough to shoot it; he would then have to carry it painfully home on his back." And we may add that unless he was unsually lucky a good deal of the meat would spoil before it could be eaten. The Paiute clothed himself after a fashion in rabbit skins, piled up brush in a wickiup to shield himself from the storm, and usually died before he was twenty-five years old. Although he lived in an extremely adverse environment, which today does not support one person per square mile, he probably is more typical of the food gatherer than the romantic cares to admit. Bilby's account of the Eskimo in Nanook of the North describes another food-gathering people living under adverse conditions. The fact that Nanook, his chief informant and the central character of the book and the film, later died of starvation puts a fitting conclusion to the account.

The Horse and the Plains Indians

The Plains Indians, like some other food gatherers, lived in a more favorable environment. But because they had no draft animals they were unable to cultivate the land extensively and raise crops that could compete successfully with the buffalo grass. In those few areas where trees killed off the grass the Indian could in turn kill the trees and for a few years get a crop from the land so cleared. In most of the prairie such cultivation methods supported only small groups of food raisers. The chief source of energy was the buffalo, which was hunted afoot with the aid of the long bow and arrow. During the summer the Plains Indians gathered into large groups for the purpose of staging a drive in which the buffalo were driven to their deaths over a bluff or into a trap. Only thus could these Indians survive in groups larger than a few households. Continuous hunting would have disturbed the grazing herds; this would have meant continuous movement of the tribe, which in turn would have led to further disturbance of the buffalo. Hence the social, economic, and political units had to be small. The physical accouterments of life were few, though more numerous than in the case of the Paiute. The "man of distinction" was the hunter. The ritual connected with coming of age was designed both to teach the arts, skills, and attitudes necessary for effective hunting and to glorify or even sanctify them.

This pattern was changed whenever these Indians captured and redomesticated the horses which had escaped from the early Spanish expeditions. The introduction of the horse into these cultures serves as an excellent illustration of the effects which the adoption of a new converter may have. It also shows how the existing culture limits the use to which a new converter will be put. Forde[9] says that "the introduction of the horse did not basically change the culture of the western Plains, but it widened the range of activities, greatly increased success in hunting and provided a wealth of food and leisure. . . ." It was also a "form of personal property which gave impetus to a wide range of modifications." As he points out, "the horse gave the ascendancy to the western nomadic hunting peoples, and the cultivators were either driven out or abandoned their more settled life and more advanced culture for the rich rewards of buffalo hunting."

Mishkin[10] goes further to show how the introduction of the horse changed what was regarded as the ideal man from one having those qualities of stoicism, patience, and skill which had characterized the hunter afoot with the long bow to one with the qualities of the daredevil rider, wielding a lance to hamstring his kill or using the short bow from horseback. In time the skilled horse thief and warrior was elevated to a position equal if not superior to that of the hunter. The size of the effective social unit changed as the advantage of the large group for protection in warfare more than offset any residual value which the small group originally had in hunting. Social organization became necessary to control these larger groups. Picked hunters frequently brought in game for the whole community. Unskilled, slow, or crippled heads of households were denied the right to hunt lest they endanger the source of food for the whole group. The relationship between responsibility for the family and ability to meet that responsibility was altered by social fiat. One squaw could not preserve all the meat or dress the hides of all the game killed by one horse-borne hunter. Since there was no change in the division of labor between the sexes, polygyny became the rule, and the accumulation of women, particularly by stealing, became a source of power and prestige.

Many of the pre-Columbian food-gathering tribes were confined to areas in which food raisers were unable to operate. As the Plains Indians acquired the horse, the energy available to them increased sufficiently to permit them to drive back the cultivators and thus extend their hunting grounds. The gain was, however, temporary. As the European settlers moved westward, bringing the harness and the plow, which enabled them to turn under the buffalo grass of the plains and replace it with crops that yielded a larger surplus, they relentlessly drove the food-gathering Indians from their ancestral homeland into less and less satisfactory areas. Here their culture was destroyed by their inability to get at the buffalo, whose energy had sustained it, and they survive today only as a colorful anachronism.

Most other food gatherers have met a like fate. Some have been able to maintain their existence by attaching themselves to agricultural regions, by gathering a product of desert, mountain, or forest, to exchange for the products of agriculture yielding more surplus energy. Some exist on sufferance in areas unfitted for incorporation into dominant civilizations, as do the Seminoles of Florida, the Eskimo, and isolated tribes in Alaska, Canada, and Greenland, and various native peoples in Africa, Asia, and South America. While anthropologists have discovered enormous differences among food gatherers, they have also shown that they operate within the limits which have been discussed above. These limits differ in some degree from those which characterize societies that Forde classifies as food gatherers. An unsatisfactory aspect of Forde's classification is that the transition from one to another means of securing food is in fact gradual. Many food gatherers raised some food or at least returned annually to the same areas where it grew naturally. Some promoted the growth of the edible plants by cutting down or killing trees whose shade reduced their fruitfulness, or by pulling weeds; these were in a limited sense food raisers. But even though what Forde called the food gatherer may not exactly typify any actual society, the "type" may serve to summarize the characteristics of those societies which modally resemble it.

FOOD-RAISING SOCIETIES

Forde's classifications apply not only to primitive or prehistoric peoples but also to modern farmers. For present purposes the category "food raiser" has most analytical significance when it is restricted to those people who are or have been almost completely dependent upon cultivated plants and/or domesticated animals for energy and those who, primarily dependent upon such sources, have secured supplementary energy through hunting wild animals and occasionally using wind or water power. Even when so restricted, "food raiser" is sometimes less useful than terms based upon other distinctions. For example, it is probable that there are more significant differences between people who are dependent primarily upon cereals grown on irrigated soil and nomadic herdsmen (who are also food raisers) than there are between those herdsmen and some of the hunters who occupy country where game is plentiful. Nevertheless, the significance of the domestication of plants and animals as contrasted with the use of these converters in the wild state is very great. Food raising represents an advance in the means regularly to provide and secure energy surpluses.

In his work Social Evolution, Childe takes the position that all civilizations derive from "the cultivation of the same cereals and the breeding of the same species of animals." Curwen has traced the use of some of the existing food plants back to very early man and has shown how the appearance of new plants causes new social relationships to emerge. We shall not here attempt either to review or to criticize the whole of the theories propounded, but the facts adduced will show both how greatly surplus can be increased through the introduction of a new plant and how greatly surplus can vary among food raisers who use the same plant.

Curwen[11] estimates that the yield in Norman England was only 6 bushels per acre from 2 bushels of seed, with a total production per person of only 15 bushels per year. On the other hand, Thurnwald[12] found that in ancient Sumeria the yield was 80 to 100 times the seed. The total amounted to "2,800 litres per hectare," or nearly 32 bushels per acre, which is not a bad yield by today's standards. It is apparent that such great variability in yield at least established great differences in the energy limits under which men lived, however they may have used the surpluses so established. The variations in environment to which cultivated plants are subjected are easily observable even in old and well-established agragrian societies. The yield from the same seed on various parts of the same field frequently varies greatly; between farmers, or more particularly between regions, there is even greater variation. The usual adverse factors take their toll in differing degrees: there may be a shortage of some of the nutrients required for optimum growth; during the growing season there may be either too little or too much total precipitation, or precipitation may come at the wrong time; there may be other organisms to contend with, both plant and animal; the very process of cultivation may be such as to reduce rather than to increase yield. Recently it has been discovered that the presence or absence of tiny traces of such minerals as cobalt and copper result in huge differences in plant yield. Where low yields are a consequence of a deficiency in minerals, the fact can now be determined and corrected; but a people dependent solely upon the energy of plants and animals could never develop the scientific knowledge necessary for the correction of such soil deficiency.

It is evident, then, that the limits imposed by the nature of the plants rarely constitute the actual and effective limits confronting those who depend upon those plants for daily living. In the first place, the land available sets limits to the amount of plant life that can be developed, whatever the character of the plants used. That plant life, in turn, sets limits upon the size of the possible population. It is comparatively easy to show, for example, that when population increases much beyond 3 persons per acre the energy derivable from most plants will not provide the means to carry out intensive cultivation and restorative fertilization which are the only methods by which so little land can be made to provide sufficient energy yields produced anywhere in the world are secured from the intense cultivation of rice by the Japanese. They produce about 2,200 pounds of rice per acre. This yields roughly 9,000 Calories per acre per day the year round. Thus, 1/3 acre would yield an average of 3,000 Calories, about what an active 150-pound man requires the year round for an adequate diet. During the period of intense cultivation he will, of course, demand more than this, but he can conserve his strength at other times. The average return from rice in India is only 829 pounds (1931-1936 average) as compared with the 2,200-pound Japanese yield. Therefore, in India a reduction in the amount of land per person below 2/3 acre reduces the energy available to a point below that necessary for survival. Soya beans or sugar beets produce more than this per acre under specified conditions, but they require supplementation by other crops and do not yield more than rice does when all the necessary factors are taken into account.

For a long time economists have been pointing to the law of diminishing returns, which sets an outer limit on the amount of food that can be produced in a given area. While they have sometimes confused the physical product of plant life with the "economic" value thereof, and have sometimes extended the meaning of the law to cover all the economic effects of limited land, no matter what its use, in essence the argument really stems from the facts to which we have just alluded. It is true that after a given point is reached a specific plant on a given piece of land will yield only so much plant product, no matter what increases in expenditure of labor or what additions to it in the form of nutrient are made. Moreover, as that limit is approached it is highly probable that a great deal of what is done is not what is required to permit the plant to reach its maximum output. Therefore, most of what is done will not yield a commensurate return or even any return whatsoever in increased energy to compensate for the energy expended. This is true even where soil is fertile and good management and plant science are used extensively. Where magic and religion and other practices interefere, the loss of energy is no doubt excessive.

In dealing with food raisers it is, therefore, necessary to distinguish between the total energy surplus which might be achieved under optimum food-raising conditions and what is actually secured under the existing conditions of man-land ratio, cultivation techniques, etc. These existing conditions can usually be improved only by the adoption of some new energy converter. The probability that a food-raising people will adopt a new converter seems to depend in considerable part upon their current ability to produce an energy surplus. In other words, the presence of an energy surplus is favorable to the adoption of a converter that will enlarge that surplus.

As Forde[13] indicates, "the range of economic and social variation among cultivators is greater than among food-gatherers, and this variability is not related in any simple way with the physical conditions." As will be shown, it is generally true that as the energy available to man increases, the variety of his activities increases. Where the energy available is only slightly in excess of that required for survival, any very great variation in behavior among those situated in any one place is impossible. Thus, whereas the variability of food raisers is very great as compared with that of food gatherers, it is small as compared with the variability of those who have larger energy surpluses. Food raising permits variability, but it also imposes limits which are reflected in some generally predictable results. Food raising decreases the time and energy spent securing food and thus permits men to do other things, but the mechanical energy available each day is still no greater than that of the human beings and the domesticated draft animals present. Food raising permits an increase in the number of persons who can be supported from a given piece of land and thus permits an increase in the surplus locally available. The increased surplus may be used in a variety of ways. It may be widely dispersed and result only in a general increase in leisure. (However, such dispersal may, and often does, lead to an increase in population, so that the land available per person is decreased to the point where each unit of land is supporting all the population that it can; when this point has been reached, there is no surplus.) The increased surplus may be used merely to increase the amount of waste. Or it may be concentrated, and the concentrated product, too, may be used in a variety of ways. It may be sacrificed to the gods. It may be buried in a tomb or destroyed at the death of a landlord or other ruler. It may be expended in the military conquest of areas which themselves yield lower surpluses. It may create a leisure class that is devoted to the cultivation of knowledge and the arts or that simply demands the continuous use of surplus in the creation of goods and services that are not productive of new arts, or knowledge, or new fixed structures. But there must be a surplus before it can be devoted to any such use.

SURPLUS AND CIVILIZATION

Civilization waited on the appearance of such energy surpluses. As Childe[14] says, civilization meant "the aggregation of large populations in cities; the differentiation within these of primary producers ..., full-time specialist artisans, merchants, officials, priests, and rulers; an effective concentration of economic and political power; the use of conventional symbols for recording and transmitting information (writing), and equally conventional standards of weights and of measures of time and space leading to some mathematical and calendrical science." All of which are impossible except where surplus energy exists in considerable quantity. As we have already indicated, Childe holds that in every case civilization grew out of the cultivation of the same plants and the breeding of the same animals. Thurnwald [15] emphasized the same general propositions. He was, however, primarily concerned with showing how such institutions as slavery and serfdom served to concentrate the surpluses of food-raising cultures in such manner as to permit the military protection of the land and the development of a class of skilled artisans and specialists, neither of which is possible where men must remain dispersed in order to gather the fruits of field and chase.

While there is considerable variation among food-raising peoples, there are also numerous likenesses among them as a consequence of the limits inherent in food raising. Among all food raisers the family is the basic consumption unit, and to a large extent it is also the production unit for much of the goods and services produced. Division of labor is limited and is primarily based on differences in skill and learning, sex, and size and muscular power. Since so large a part of what must be done requires merely brute strength, there are also likely to appear status differences which assign whole sections of the population to physical tasks without regard for the potential skill, intelligence, strength, or sex of individuals. If the emergence of complex institutions depends upon the development of a surplus, so too the development of a surplus depends upon the existence of such institutions. Once a balance is attained, however, it is difficult to upset.

The Egyptians: An Example

The Egypt of the age of the Pharaohs provides a good demonstration of the working of a balanced system in which a comparatively small energy surplus is utilized in such a way that there is no disturbance to the energy-producing procedures. The Egyptians left a durable record of their accomplishments, and these records have been subjected to a great deal of study. The Egyptian system operated, moreover, under unique physical circumstances which precluded a disturbance of the balance through soil exhaustion. The Nile regularly replaced the soil and continuous cropping caused no depletion. The deserts, sea, and river cataracts formed barriers which could be crossed by an invader bent on conquest and plunder only with great expenditure of energy surpluses. The Egyptians were, under these favorable conditions, able to push food raising to a climactic * stage.

During long periods of its history the surpluses of Egypt were absorbed by the burial mounds or pyramids. These contain both direct and symbolic evidence of Egyptian accomplishments. During the reign of some of the Pharaohs almost the total surplus of the people was concentrated in the erecting and furnishing of the pyramid which was to honor the ruler upon his death. The ruling class was small and consumed no great amount of wealth, for the chief objective of its way of life was to accumulate surpluses to be taken into death. The population was held constant or even diminished, since men were worked to death about as fast as they could be brought to maturity. Even so, the surpluses were never great. The Cheops pyramid, together with its furnishings, absorbed all the surplus energy produced during the lifetime of about 3

* This word is applied here in much the same way that it is used by ecologists. It indicates the culminating stage of the possible development in a region, given a limited set of plants and animals to begin with and assuming no major alteration in geographic conditions. We imply that given sufficient time the use of low-energy converters results in a type of persistent equilibrium between men and their environment.

million people. During a 20-year period 100,000 slaves are said to have worked to produce the tomb. This was about 1/25 of the total population. We can calculate, then, that those who supplied the food to keep the pyramid builders alive each contributed only about 100 to 150 Calories a day. Thus, although the Egyptians enjoyed most favorable geographic circumstances, the total energy available to them was by modern standards extremely low, however high it may have been in comparision with the energy production of other societies of the time.

At other periods in its history the surpluses enabled Egypt to engage in conquest of all its neighbors. At still other times the surplus was exhausted in conspicuous expenditure and display among the living; at those times when controls over population broke down, the surplus was completely exhausted in civil war or by the increase in the number of mouths to be fed from the land.

It is possible to calculate the distance from their base on the Nile that the Egyptians could have advanced had they been willing to devote all their surpluses to conquest of neighboring peoples. The size of the surplus was one limiting factor: the surplus has to be carried or pulled from Egypt by men or asses. At some distance from the Nile the energy costs of transportation would have reduced the surplus derived from Egypt to a point below that available to the people being invaded, and Egyptian expansion would at this point have been checked. The topography and the resources of the region invaded, the will to resist and the military technology, strategy, and leadership of its inhabitants also would have been involved in fixing the ultimate limit to which the Egyptians could have advanced. Similarly, the possible spread of Egyptian culture was limited by its capacity to yield surplus under the very different conditions that prevailed outside Egypt. Egyptian culture was adopted elsewhere only with great difficulty. When Egypt did conquer a people, it was seldom able to assimilate them. And when conditions in Egypt led to disorganization, the conquered people usually broke away and resumed their previous way of life. Such a resumption is reported in the Biblical story of the exodus of the Jews from Egypt.

The peoples of the Fertile Crescent contributed much to what we now regard as civilization. But the extent of their political holdings, the range over which they were able to secure and maintain cultural homogeneity, and the diversity of their skills and knowledge were slight by present standards. Their history shows cyclical variations within constant limits. The abuses of one system gave rise to another system, which in turn was defeated by its own weaknesses. None of these systems could, however, exceed the limits imposed by the basic converters, that is, plants and animals. And these same basic converters are depended upon by the greater portion of the people of the world today. Moreover, the cultures of the rest of the peoples of the modern world were developed in considerable part under the limitations imposed by the plant-animal-man system.

CURRENT LOW-ENERGY SOCIETIES

Societies such as those that now exist in India, Africa, and China have been greatly modified by the introduction of new converters but are still closely restricted by the limited energy which they have available. The population is in many of these areas so great that local resources will not supply an adequate diet.[16] In Yünnan, for example, about 100 families (500 to 600 people) share 150 acres. This is about all the people that plant life will support if the plants are eaten directly. Buck[17] found that in the 1930's nearly 90 per cent of the potential farm area of China was in crops, while only 1.1 per cent was in pasture. By comparison, in the United States 42 per cent is in crops and 47 per cent is being used to pasture animals. Moreover, in the United States much of the crop land is used for feed rather than for food. The energy available from animal power in China was and probably still is close to zero, and the limits on the mechanical energy available in many Chinese villages might be ascertained simply by multiplying the number of persons by 20 per cent of the heat value of the per capita food intake.

Under these circumstances the energy costs of transportation between village and field would cut deeply into the available surplus if the distances were great. Consequently villages are very small and located at frequent intervals. When the small surpluses available have been used to support centralization of control, the effect of that control on energy production has rarely been equivalent to its cost. Even the introduction of new sources of supply has tended to affect the old system adversely. For example, many Chinese villages had long paid their taxes and bought necessary imports by converting the leaves of the mulberrry trees along the canal banks into silk. When the Central Government was forced by foreign powers to protect trade in Japanese silk, American cotton, and British Commonwealth wool, many villages lost this source of income and were confronted by a great change in their way of life. Often the land was sold to pay taxes, and city people gained control over it. The consequences here was a great increase in tension between town and country, absentee owner and tenant, and an intense effort to restore the earlier balance. The present turmoil in China evidences both the efforts of the Communists to achieve greater centralization, which upset the balance still further, and their efforts to restore to the peasant control over the land he cultivates and to the village the self-subsistent economy which trade upset.

India shows many of the same characteristics. The average net cultivated area per capita of agricultural population in Bengal in 1939 was less than 1 acre, and 46 per cent of farming families had less than 2 acres each.[18] The tillable land of India is supporting the maximum number of people which it can maintain with the energy that is obtainable from it with existing practices. If higher demands are made on the soil, it will pass the point of diminishing returns. Here also the village community serves as the predominant spatial and functional unit. It supplies almost no surplus beyond that required for the local institutions themselves. The energy costs of national government or more extensive social organization must be provided by other energy sources. In the past much of the energy used for these purposes was imported from Britain in the form of goods produced with British coal and water power.

In some areas that have used only organic sources for energy the population has been limited at a point short of that which characterizes the "overpopulated" parts of China and India. However, as land becomes scarce in relation to the population, the tendency has been for more and more intensive cultivation to be undertaken. This has frequently resulted in an effort on the part of each farmer to increase the only productive factor over which he himself has control, namely, children. As a consequence, even greater pressure has been put upon the soil and even less energy has been available to devote to the development of new agricultural techniques or the enlargement of the area under cultivation.

Among the Bantu in Africa[19] it is the labor of clearing the land that sets limits on cultivation. Every child thus becomes an economic asset, and there is continuous emphasis on increasing the size of the family. However, life is there so precariously balanced that a crop failure is likely to result in starvation and a reduction in the working population in the next crop cycle. This is also the case in at least some parts of China. In a village in Yünnam, Fei and Chiang found that the size of a farm that can be worked by a man and his wife alone is too small to support a family. As a result children must work; in the absence of children the older adults will starve.

Economic reciprocity between parents and children tends to become a necessity in societies that are dependent on organic converters. Children supply in these areas what is secured in industrial societies through unemployment, health, and disability insurance, and old-age allowances. Parents develop in the child values that will ensure their own survival, and the commandment "Honour thy father and thy mother: that thy days may be long upon the land..." is a statement of a functional relationship.

THEIR CONSERVATISM

Since the limits within which low-energy societies operate are so narrow, extensive conflict and its concomitant wastes cannot long be tolerated. Hence institutions develop which tend to reinforce rather than to weaken each other. The introduction of any new element is likely to be disastrous to one or more of the parts making up the web of the culture. When this happens, the traditional allocation of scarce resources is threatened, since men then no longer learn from all the sources of authority the same design for the "good life". As a consequence, resistance to change frequently amounts as the ramifications of change appear. Moreover, change is often introduced into low-energy societies by "outsiders" who have their own reasons for inducing it. Frequently such change provides a more satisfactory way of life for only a few of the "natives", while others are forced to bear costs which they consider totally disproportionate to any foreseeable gains. Those members of the society who value very highly certain of the gains to be made through the introduction of new converters, welcome change and encourage it. For others, whose pastoral and agricultural values are thereby destroyed, the "material benefits" which accompany the use of the new converters are not adequate compensation for the values lost, and they struggle to preserve the system that is jeopardized by the introduction of the new converters. Even in the highly industrialized United States of today there is great respect for the virtues of the husbandman and for the rural institutions which support and are supported by many American ideals. For example, the "family-sized farm" is widely held to be necessary to democracy, Christianity, and individualism.

Thus low-energy societies offer more barriers to change than just those imposed by cost of securing the new converters needed to effect change. Added to these are the cost of social disorganization and of purposeful resistance. If these barriers are to be overcome, there must be considerable energy in the hands of those who seek to bring about change. Since, as we have indicated, most of the energy available in low-energy societies rests in the hands of those with traditional social claims to it-for example, peasants, landlords, and others who will not want such change—a great increase in energy is necessary in order to provide a surplus adequate to secure the introduction and use of new converters. In a low-energy society change must come slowly, for the range between the most and the least effective use is not, by modern standards, great. Therefore the conquest of users of low-energy converters has frequently meant that the surplus produced merely passed from the hands of one group to another, its size remaining relatively constant and the culture remaining basically unchanged. Such drastic changes as the engulfment of the Plains Indians in the United States have been possible only with the extensive use of converters that were far more effective in delivering surplus energy than those that existed prior to the conquest.

In the main, then, the low-energy system of a people dependent wholly on food raising is inherently self-perpetuating. It develops a balance between population numbers, social institutions, energy usages, and energy production which is exceedingly difficult to disturb and which, if disturbed, tends to reassert itself. As a consequence, the impact of modern industrial technology on peasant societies is far weaker than is generally assumed, and those who have endeavored to introduce new converters to such peoples have had limited success.

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" THE NATURE AND CHARACTERISTICS OF ENERGY "

" ORGANIC ENERGY AND THE LOW-ENERGY SOCIETY"

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