ENERGY IN PERSPECTIVE

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PREFACE

In 1973 we suddenly became aware that we are in the midst of an "energy crisis." The point was brought home dramatically when the Arab countries of the Middle East—one of our important sources of imported petroleum—suspended all shipments of oil to the United States just before the onset of the winter season. This abrupt change in the petroleum supply hastened our awareness of a situation that was already upon us. Even without the Arab embargo on oil shipments, our fuel supplies were not in a healthy condition. Supplies were (and are) dwindling and costs were (and are) rising. Fuel stocks, particularly those of gasoline, fuel oil, and natural gas, are no longer sufficient to permit the extravagant use we have enjoyed in the past. Several inconveniences are already upon us, with predictions of more severe conditions—even hardships—in store. We have experienced shortages in the supplies of gasoline and fuel oil, and have had conservation measures thrust upon us in the form of mandatory fuel allocations. Increased use of air-conditioning equipment during a severe summer heat wave often overtaxes our electrical generating plants and necessitates cutting back the power output, producing a "brownout."

These experiences make it natural to wonder what our prospects are for the future. How long will our fuel supplies hold out? What new possibilities are there for alternate sources of energy? What new technologies are developing that might alleviate our energy problems?

In this book we attempt to place the "energy crisis" in perspective. We will discuss where our energy comes from, what we do with it, and the projections for the future. We will be concerned primarily with the patterns of energy consumption, the fuels required to produce this energy, and the effect that energy usage is having on our environment. We will examine the overall situation and will discuss both the short-term problems and the long-term outlook. We will devote the major attention to questions of fuel supplies and new energy technologies, and not to crisis remedies such as gasoline rationing, reduced speed limits, and fuel oil allocations.

It is not our purpose here to describe the operating characteristics of the many devices that are used to convert the energy content of fuels into useful forms of energy. We will therefore not discuss the details of electrical generating equipment, storage batteries, fuel cells, or solar converters. However, because nuclear power looms as such an important factor in our future energy picture and because some of the problems associated with nuclear power are unique and challenging (and often misunderstood), we have elected to present some of the details of nuclear reactor operations and their effects on Man and his environment.

As we look at the overall energy picture, we immediately see that we are confronted with a formidable problem in analysis. In order to discuss the energy situation, we must engage in an exercise of "futurism." How much energy will we need in the year 2000? In the year 2050? How much fuel can be extracted from the Earth by these dates? What new technologies will be available in 25 or 75 years? Clearly, we do not know the answers to these questions with any degree of certainty. Nevertheless, projections must be made to guide our thinking and our actions. We will discuss some of these estimates and predictions. In doing so, we will use various facts and figures concerning energy consumption, power production, and fuel reserves, as well as projections of future requirements. When reading these sections, it must be understood that none of these figures is precise. The futurism of energy is an uncertain business.

We cannot give here any clear-cut solutions to our energy problems. (Indeed, there *are* no clear-cut solutions to these problems.) The aim is to present a guide to our recent experience with the utilization of energy and to give some indications of both the challenges and the prospects that the future holds. In some cases we will present the worldwide outlook, but generally we will be concerned with the situation in the United States.

It should be noted that this book is intended for use in classroom courses as a text or supplementary text and for individual reading. It is not intended as a sourcebook of new and authoritative data. The figures, estimates, and projections given here are not original; instead, they represent what the author believes to be the most reliable information and the most reasonable projections available at present. In many cases, the published figures have been averaged or have been adjusted to reflect the passage of time since the original publication. Consequently, the source for a particular item is not always given.

In this limited survey, we cannot give a complete summary of the extensive volume of energy data and projections. With regard to estimates of future energy needs, for example, somewhat different assumptions (different *scenarios*) will, of course, produce different results. In such cases, the intermediate view is presented and only occasionally is mention made of the extreme positions on either side. This book, therefore, represents a kind of average picture of a very complex subject.

Chapter **1**

THE ENERGY CRISIS

We often hear the term "energy crisis" used these days. But what *is* the energy crisis? Is the world actually in danger of running out of useful energy? Are we faced with the prospect of darkened cities, curtailed transportation, and no heat for our homes? In reality, the world's energy resources are plentiful. The reserves of coal are sufficient for several hundred years; we receive vast amounts of energy from the Sun; there is a huge and almost untapped reservoir of heat within the Earth; and the supply of nuclear fuels is almost unlimited. Why, then, is there a "crisis" at all?

THE NATURE OF THE CRISIS

Much that has been written or spoken about the energy crisis—especially about the way energy consumption affects the environment—has been influenced by emotion. But if we are to solve our energy problems, it must be through enlightenment, not through wishful thinking. In this review the attempt is made to provide a dispassionate view of the situation. Problem areas are identified and prospects are presented. Some indications are given of the directions in which we must proceed if we are to overcome the crisis.

The energy crisis is a complex series of problems—scientific, technological, social, economic, and political. Many factors conspire to produce a potential (or actual) shortage of energy even though we are surrounded with a plentiful supply. First of all, the demand for energy is increasing at a rapid rate. There are two separate reasons for this. Not only is the world population steadily rising, but the individual (or per capita) demand for products and services is increasing. Affluent nations require more and more energy to maintain or to advance their standards of living. And emerging nations require more and more energy to convert from agricultural to industrial economies. Even agricultural activities demand increasing amounts of energy (for fertilizer production and for mechanized equipment) to meet the world's food requirements. In fact, the world demand for energy is doubling every 15 years or so.

Increased demand for energy is itself not a factor of great concern if there is no shortage of supply. However, there *is* concern over the undesirable side effects brought about by increased usage of energy. The second factor contributing to the energy crisis is, therefore, the adverse effect on the environment due to the extraction, the transportation, and the utilization of our fuel supplies. Efforts are being made to reduce the spoilage of the world we live in by our increased usage of energy. But every such effort, as desirable as it may be, places some kind of restriction on the utilization of energy and makes it more difficult (and more expensive) to supply users with the amounts of energy they require. Moreover, the nature of the restriction itself generally results in an expenditure of energy (as, for example, in the regulations that require strip-mined lands to be restored).

Although we can see around us plentiful supplies of energy, only a small fraction of this energy is in a directly useful form. The rushing waters of a river represent a substantial amount of energy, but this energy becomes available to light our homes only if a hydroelectric plant is constructed on the river. We know that there are huge reserves of petroleum that lie buried beneath the sea only a few miles from many of our coasts. But before this natural petroleum can be used to power our automobiles, it must be located, drilled for, refined, and transported to the local gasoline station. More and more, the conversion of our energy supplies into useful forms is falling behind the pace at which the energy is required. Even before the Middle East embargo on oil shipments, we had experienced some shortages of fuel oil, gasoline, and natural gas. And the "crisis" is very likely to become worse before we see any really significant, long-term improvement.

The next factor is a geographical one. The sources of our most widely used fuels are not usually located near the places where energy is actually needed. Most of our coal, oil, and natural gas must be transported over great distances. For example, some of the richest reserves of oil in the world are located in the Middle East. Oil from the countries in this region is shipped in large quantities by tanker to North America, Europe, and Japan. The expense of transportation adds to the cost of our fuels, and if the demand for oil increases more rapidly than production is increased or new tankers and pipelines are constructed, it may become impossible to move oil in the quantities required.

Geopolitics is a factor that is closely related to the geographical factor. If a nation depends heavily on a fuel that is supplied by another nation, it is always conceivable that a deterioration in the international political situation could suddenly cut off the supply. In early 1973 the United States imported about one-third of the oil that it used; about one-quarter of these imports were from Arab countries in the Middle East. Because of the easy availability of imported oil and because of the restrictions on the burning of coal, oil has almost completely replaced coal as a fuel in electrical generating plants along the East Coast. Most of the oil used in these plants is imported. Any reduction in the amount of imported oil therefore places severe burdens on these generating facilities, as it did in 1973-1974. Fortunately, the United States is not dependent primarily on any single country or region for its imported oil. (Most of our foreign petroleum now comes from Canada, Nigeria, Iran, and Venezuela, but the Canadian exports will be phased out during the next several years.) Western European countries and Japan are in a much more vulnerable position: They import nearly 90 percent of their oil from the Middle East and Africa. In the aftermath of the 1973 Middle East War, it became forcefully evident that concerted action by the Arab states in controlling the export of petroleum can be an important weapon in international politics.

Finally, there are several factors of an artificial nature, including various laws and regulations that contribute to the growing problem of supplying energy in the amounts demanded. We recognize the regulations affecting the environment and human safety as necessary and desirable. Other regulations, such as the way in which fuel prices are regulated by the Federal Government, are more difficult to understand and appreciate. A few of the factors are:

1. In order to meet the Federal air quality standards regarding the emission of sulfur dioxide fumes, it is no longer possible in many localities to burn coal because of the high sulfur content of certain types of coal. Although coal is our most plentiful chemical fuel, many electrical generating plants have been forced to convert from coal to oil so that sulfur emissions can be held to a minimum. Moreover, the regulations on exhaust emissions from automobiles have forced the introduction of control devices which, although reducing emissions, also decrease the operating efficiency of the engine, with the result that more gasoline is consumed. These regulations have therefore placed an even greater burden on our oil supplies.

2. Coal from deposits that lie near the surface can be stripped off much more easily and inexpensively than coal that has to be extracted from deep mines. Although there exist large quantities of coal in the United States that can be efficiently removed from the Earth by strip-mining techniques, these methods have often despoiled the land to a serious extent. New regulations will require strip-mine operators to devote considerably more effort to re-

claim mined land. The result of these regulations is certain to increase the cost and perhaps will limit the supply of strip-mined coal, our most accessible fuel.

3. The least offensive of our fuels, in terms of the pollution that it produces, is natural gas. Unfortunately, the reserves of this fuel (in terms of the energy content) are far smaller than those of coal. At the present time in the United States, the price that can be charged for natural gas by the driller is limited by government regulation to an artificially low amount. Drillers are therefore reluctant to undertake expensive exploration and deep-well drilling in order to increase the production of natural gas. (It is expected that these controls will be lifted in the near future.) Because of low supplies, most gas companies have stopped expanding their service to new customers and, on occasion, have been forced to curtail service in some areas.

4. Vast amounts of oil are locked in the extensive deposits of shale found in the states of the Northern Plains and in the tar sands of Canada. We now have no practical method for extracting this oil. In spite of the richness of these deposits, and even though a pilot plant has been operated, only very recently has serious attention been given to developing an economical method for adding this oil to our supply.

5. As our supplies of coal, oil, and natural gas dwindle, we must place an increasing emphasis on the use of nuclear fuels in the generation of electrical power. Although nuclear fuels will not be the major source of our electrical power in this century, they will probably become so within 25 to 50 years. As more and more nuclear power plants are planned and built, it has become increasingly difficult to obtain public acceptance for these plants. The result has been a significant slowdown in bringing new generating facilities into operation. During periods of high usage of electrical energy, the existing plants are often called upon to deliver peak capacity. Any failure during a period of small or no reserve capacity means a "brownout" or a "blackout."

In retrospect it seems obvious that we should have begun years ago to address ourselves to the problem of energy supply. But as long as we could flick a switch and have as much electrical energy as we needed, and as long as we could drive to any gasoline station and fill our tanks, there seemed to be no problem at all. With shortages now appearing, we finally realize that there is indeed an "energy crisis." In 1973 we began to take some of the positive steps that are necessary to meet the energy challenge. Research monies are being made available to investigate alternative sources of energy, with the expectation that billions of dollars will be expended during the next few years. The main efforts with regard to conventional fuels will be directed into three areas: (1) the conversion of coal into gaseous and liquid fuels (coal *gasification* and *liquefaction*) in order to eliminate the noxious fumes and smoke that result from the burning process, (2) the extraction of oil from shale deposits, and (3) the removal of a significantly greater fraction of oil from tapped oil deposits (at present an average of only about 30 percent of the oil in a field is actually extracted). In addition, increased research and development will be carried out toward making breeder reactors and fusion reactors operational parts of the energy supply and to investigate alternate sources such as solar and geothermal power.

THE FUTURE—BRIGHT OR BLEAK?

What will our world be like in 1985 or 2000? Will the problems of supplying energy finally have caught up with us? Will the many facets of the energy crisis have proved too much for Mankind to handle? Will we be forced into a worldwide austerity program with regard to energy and, consequently, with regard to our standard of living? Or, will we have solved our energy problems so that we will have inexpensive and plentiful supplies to run a world even more dependent on energy-hungry high technology?

Our problem for the future is twofold. First, we are in no immediate danger of exhausting our supplies of conventional fuels (coal, oil, and natural gas) or of uranium, the primary nuclear fuel at present. But although the natural supplies are still abundant, it is becoming increasingly difficult to extract these fuels from the ground and to deliver them to the consumer in the quantities demanded. Moreover, we must learn to use these fuels in ways that do not seriously degrade our environment. We cannot expect that the mining of coal, the drilling for oil and natural gas, or the burning of these fuels will ever be accomplished with *zero* effect on the environment. Nor will a nuclear fission reactor ever be built that will not produce substantial amounts of potentially dangerous radioactivity. But we can hope that ways will be found to reduce the degradation of our world and its atmosphere to levels that will permit us to continue to enjoy our energy-rich planet.

Second, the long-range problem involves developing new sources of energy. At some time in the future, we *will* have depleted the coal, oil, natural gas, and uranium resources of the world to the point that we can no longer rely on these fuels as major sources of energy. The three primary but so far undeveloped new sources of energy for the future are solar energy, geothermal energy, and nuclear fusion energy. In each case we know in principle how to extract and use the energy, but the technology to do so on a large scale does not now exist. We discuss each of these new energy sources later in this book; briefly, the situation is as follows.

At a few places in the world, hot underground water is piped to the surface and is used to heat homes and to drive electrical generators. Although the amount of heat energy within the Earth—geothermal energy—is truly enormous, we have no idea at present how this energy might be made available on a widespread basis.

Solar energy appears to be somewhat more promising. Various proposals have been made to construct "solar farms," huge arrays of special materials that convert the energy in sunlight into electrical energy. In all schemes to utilize solar energy, we must contend with the fact that the incoming energy at any time is spread over the entire sunlit part of the world and is not concentrated conveniently in any one place. In order to collect sufficient sunlight so that the electrical output is comparable with a conventional power plant, an extremely large area must be covered with sunlight converters. Although we know how to convert solar energy into electrical energy on a small scale (this is routinely done, for example, with solar cells on spacecraft), the technology does not yet exist to utilize solar energy on a large scale.

Probably the brightest hope for the future lies in fusion power. Energy is released whenever two nuclei with small masses are made to fuse together into a single, more massive nucleus. In the ocean waters, there is an almost unlimited supply of deuterium (heavy hydrogen) which, together with the abundant metal lithium, can serve as nuclear fusion fuel. Extremely high temperatures (measured in millions of degrees) are required to force nuclei to undergo fusion. We have not yet been able to discover a way to confine the fuel materials at these temperatures and to extract useful amounts of fusion energy. Substantial progress has been made in understanding the behavior of matter under fusion conditions, and the prospect is that we will have a prototype fusion power plant in operation before the end of this century. If the development of fusion power is in fact successful, we can look forward to the time 50 or so years hence when electrical energy will be produced cheaply and cleanly and will be available on a widespread basis.

We cannot be certain that our hopes for fusion power (or for solar or geothermal energy) will actually be realized. In any event, these new sources cannot be developed in time to alleviate shortages of the type we are now experiencing. At best, these sources represent long-term developments. If the technical problems cannot be solved before we exhaust our supplies of conventional fuels and of uranium for nuclear fission power plants, we will then be faced with an energy crisis of enormous proportions. For this reason, development of an interim or backup energy source is under way in the form of *breeder reactors*. Fission reactors of the type now used in nuclear power plants consume uranium fuel. A breeder reactor is a fission reactor in which nuclear energy is released and at the same time new fuel is produced from initially nonfissionable materials. Because new fuel can be produced from materials that are abundant in the Earth's crust, breeder reactors could supply us with power long after the more limited supplies of uranium are depleted. The Soviet Union and France already have breeder reactors producing electrical power, and the United States has embarked upon a program to develop commercially viable breeder reactors by the mid-1980s.

In the following chapters we examine in greater detail the points raised in this introductory discussion. We consider how we use energy, our changing patterns of energy supply, and the consequences of using energy in various forms.

Chapter 2
WORK, ENERGY, AND POWER

We all have some intuitive notions about the quantity that is the central topic of this book—*energy*. We know that we must buy gasoline to supply the energy that runs our automobiles, and we pay a monthly bill to the electric company for the electrical energy that is delivered to our homes. We understand that coal, oil, and gas play important roles in supplying the energy that is necessary for our everyday living. But to pursue our topic in detail we need more than these qualitative ideas. We need to understand some of the basic physical principles that govern situations involving energy.

Before we can begin a meaningful discussion of energy problems, we must establish the language we will use. That is, we must define the terms and the units that are necessary to describe various situations involving energy. We will require only a few of the large number of the terms that apply to physical quantities—primarily, *work, energy,* and *power*. The units we will use are *metric* units—meters, kilograms, and seconds, as well as a few derived units such as watts and kilowatt-hours. Thus, we will employ only a limited vocabulary, one designed to cover only the situations of immediate interest.

THE DEFINITION OF WORK

We frequently use the term *work* in ordinary conversation. We might say, for example, "That job requires a great deal of work." What does "work" really mean here? If you lift a number of heavy boxes from floor level and place them on a high shelf, you will feel tired after the job is completed—you will know that you have done *work*. This is exactly right. Gravity pulls the boxes downward and when you lift the boxes, you are doing work against the gravitational force.

In its physical meaning, *work* always involves overcoming some opposing force. Suppose that instead of lifting one of the boxes, you push it across a rough floor. In this case, you are not working against the gravitational force—the box is at the same height throughout the movement. Instead, you are now working against the frictional force that exists between the moving box and the floor.

How do we measure work? The amount of work done in any situation depends on how much force was exerted and on how far the object moved. Increasing either the applied force or the distance through which the object is moved increases the amount of work done. That is, the work done is proportional to both the applied force and the distance through which the force acts (Fig. 2.1). The equation which expresses this statement is

$$\boxed{\begin{array}{l}\text{Work} = \text{force} \times \text{distance} \\ \quad W = F \times d\end{array}} \tag{2.1}$$

In this equation, d stands for the distance of movement, measured in meters (m), and F stands for the applied force. According to Newton's law of dynamics, $F = Ma$, the force F necessary to impart an acceleration a of 1 meter per second per second (1 m/s^2) to a mass M of 1 kilogram (1 kg), is 1 $kg\text{-}m/s^2$. To this unit we give the special name, 1 newton (1 N). Therefore, in Eq. 2.1, we have

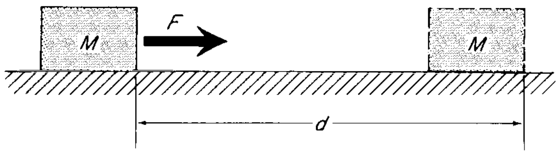

Figure 2.1 The work done by the force F is $W = Fd$.

F = force (in newtons)

d = distance (in meters)

W = work done (in newton-meters)

We give to the unit of work the special name *joule*:

$$1 \text{ joule (J)} = 1 \text{ newton-meter (N-m)} \quad (2.2)$$

How much work must be done to lift a block of mass M through a vertical height h? In this case, work is done against the gravitational force. The magnitude of this force is the *weight* of the object and is given by Newton's equation $F = Ma$, when we identify a as the acceleration due to gravity. We usually indicate the gravitational acceleration by the symbol g, so that the expression for the weight of an object (the gravitational force acting on the object) is

$$\text{Weight,} \quad w = F_{grav} = Mg \quad (2.3)$$

The value of g on or near the surface of the Earth is 9.8 m/s^2.

Now, we can use Eq. 2.1 to write the work required to lift a block of mass M through a vertical height h:

$$W = F_{grav} \times d = w \times h = Mgh$$

That is,

$$\boxed{\text{Work done in raising an object,} \quad W = Mgh} \quad (2.4)$$

If the mass is M = 10 kg and the height is h = 3 m, the work done is

$$W = Mgh$$

$$= (10\ \text{kg}) \times (9.8\ \text{m/s}\ ) \times (3\ \text{m})$$

$$= 294\ \text{J}$$

A mass of 1 kg corresponds to 2.2 pounds (lb) and 1 m is a bit more than 3 feet (ft). Therefore, the amount of work done in this example corresponds approximately to that required to lift a 22-lb mass to the height of a basketball basket (10 ft).

ENERGY

When an object is moved against a force, work is done and *energy* is expended in the process by the agency responsible for the movement. Thus, we say, "A person must have a lot of energy to do a hard day's work." In fact, one way to define energy is

Energy is the capacity to do work.

Suppose that a cart is rolling at constant velocity v across a floor and strikes a block at rest on the floor (Fig. 2.2). As a result of the collision, the block will

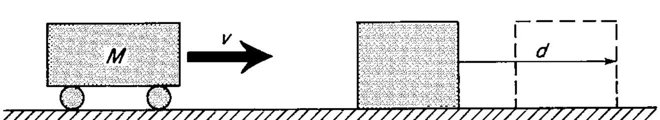

Figure 2.2 The kinetic energy of the moving cart is transferred to the block in a collision and the block slides across the floor. The sliding block does work against the frictional force.

slide a certain distance d across the floor before coming to rest because of friction. The sliding block has moved against the frictional force and has therefore done a certain amount of work.

The block moved and did work because energy was supplied to it by the moving cart. The energy that an object possesses *by virtue of its motion* is called *kinetic energy*. The more massive the object is and the faster it moves, the greater is its kinetic energy. The expression for the kinetic energy of an object with a mass M moving with a velocity v is

$$\boxed{\text{Kinetic energy,} \quad \text{KE} = \frac{1}{2} Mv^2} \qquad (2.5)$$

Notice that the kinetic energy depends on the *square* of the velocity. A block moving with a velocity of 16 m/s has a kinetic energy *4* times greater than when it is moving with a velocity of 8 m/s.

What is the kinetic energy of a 12-kg object when it moves with a velocity of 7 m/s? Using Eq. 2.5,

$$\text{KE} = \frac{1}{2} Mv^2 = \frac{1}{2} \times (12 \text{ kg}) \times (7 \text{ m/s})^2 = 294 \text{ J}$$

which turns out to be exactly enough energy to raise a 10-kg object to a height of 3 m, as we found in the preceding section.

Notice that kinetic energy and work have the same units, namely, *joules*. We can see this more clearly by writing the units for the various physical quantities in the expressions for work and kinetic energy:

$$\begin{aligned} \text{Work} &= F \times d \\ &= (\text{N}) \times (\text{m}) \\ &= (\text{kg-m/s}^2) \times (\text{m}) \end{aligned}$$

$$= (\text{kg-m}^2/\text{s}^2)$$

$$= (\text{J})$$

$$\text{KE} = \frac{1}{2} Mv^2$$

$$= (\text{kg}) \times (\text{m/s})^2$$

$$= (\text{kg-m}^2/\text{s}^2)$$

$$= (\text{J})$$

In the preceding section we considered lifting a mass M to a height h. We found that the work done in such a case is $W = Mgh$. The object was originally at rest and in its final position the velocity is again zero. Thus, no kinetic energy was imparted to the object. But the object has a capability to do work that it did not have in its original position. For example, if we drop the object and allow it to fall through the height h, work can be done in driving a stake into the ground (Fig. 2.3). That is, the raised block has the *potential* to do work and we call this capability the *potential energy* of the object:

$$\boxed{\text{Potential energy, PE} = Mgh} \qquad (2.6)$$

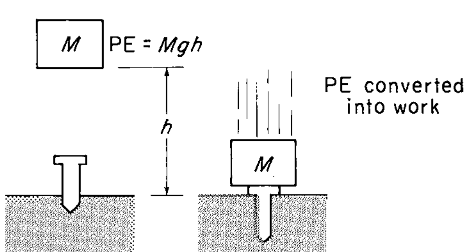

Figure 2.3 The potential energy of a raised block can be converted into work.