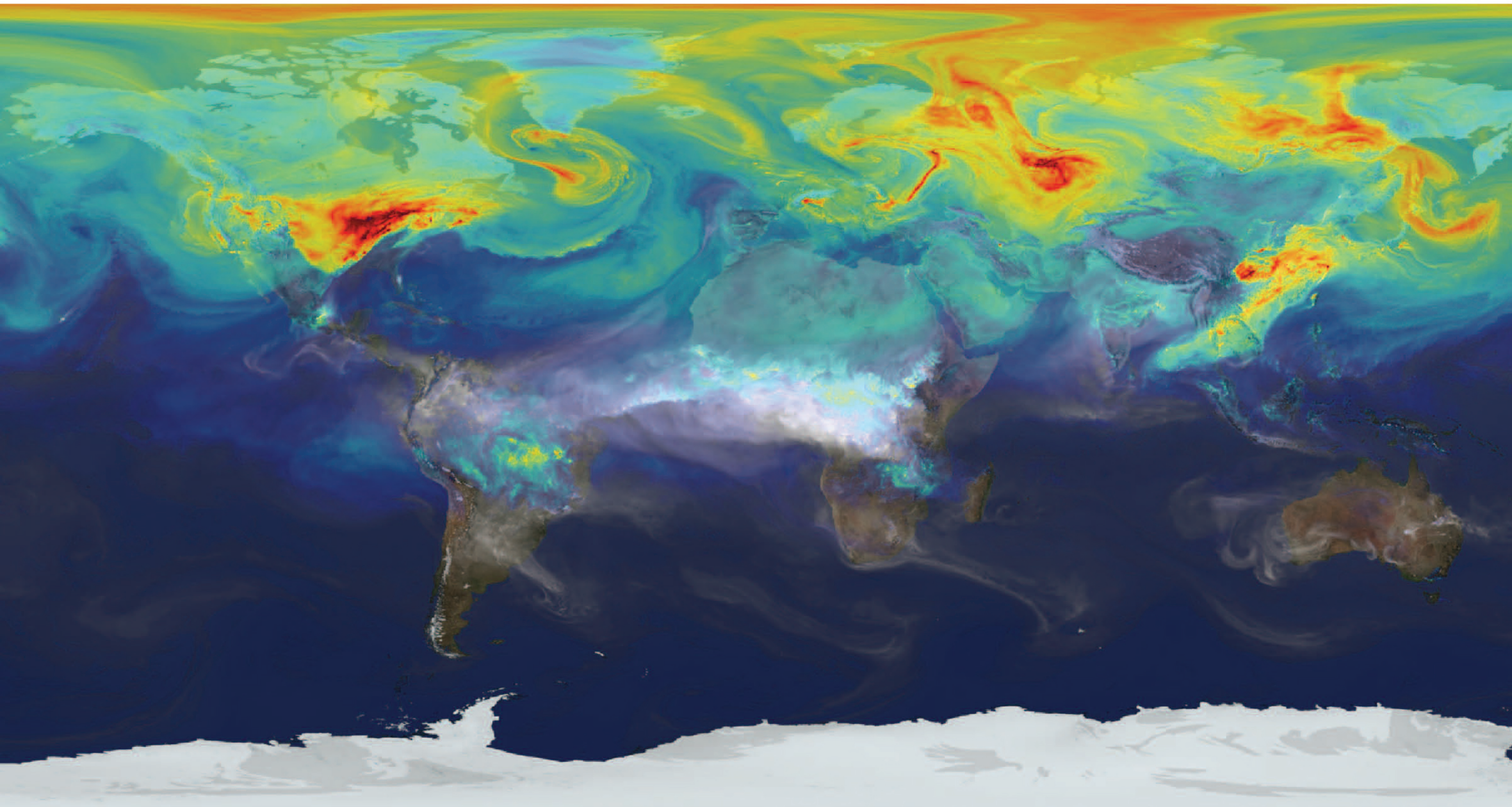
Energy and the Environment

Third Edition

ROBERT RISTINEN | JACK KRAUSHAAR | JEFFREY BRACK



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Cover photo: A frame from "NASA | A year in the life of Earth's CO2," a visualization of global carbon dioxide flow in the atmosphere. The video was generated by a high-resolution computer model called GEOS-5, created by scientists at NASA Goddard's Global Modeling and Assimilation Office.
Credit: NASA's Goddard Space Flight Center; http://svs.gsfc.nasa.gov/goto?11719

MISCELLANEOUS FACTORS

1 centimeter = 0.3937 inch; 1 inch = 2.54 cm

1 micron (mm) = 10^{-6} m

1 meter = 3.28 ft; 1 foot = 12 in. = 30.48 cm

1 hectare (ha) = 10,000 m^2 = 2.471 acres

1 acre = 43,560 ft^2 = 0.4047 ha

1 liter = 1000 cm^3 = 0.264 gal

1 gallon = 0.1337 ft^3 = 3.785 liter

1 acre foot = 325,804 gallons

1 cord = 128 ft^3 = 3.624 m^3

1 barrel (bbl) = 42 gal = 159.1 liter

1 kilogram = 2.2046 lb; 1 pound = 16 oz = 0.454 kg

1 therm = 100,000 Btu

1 watt = 1 J/sec = 3.41 Btu/hr

1 kilowatt = 1000 J/sec = 239 cal/sec = 3413 Btu/hr = 1.341 hp

1 horsepower = 550 ft $\cdot$ lb/sec = 746 W

1 year = 3.15 = 10^7 sec

density of water = 1 g/cm^3 = 62.4 lb/ft^3

density of gasoline = 0.70 to 0.78 g/cm^3; average = 0.72 g/cm^3

density of diesel fuel = 0.82 to 0.95 g/cm^3; average = 0.85 g/cm^3

density of propane = 0.50 g/cm^3

density of air at STP = 1.293 kg/m^3

heat capacity of air = 1000 J/kg $\cdot$ K = 0.019 Btu/ft^3 $\cdot$ °F

ASTRONOMICAL DATA

Mean radius of earth	6.371×10^6 m
Mass of earth	5.975×10^{24} kg
Surface temperature of earth	290 K
Mean distance from earth to sun	1.49×10^{11} m
Mass of sun	1.99×10^{30} kg
Surface temperature of sun	6000 K
Radius of moon	1.741×10^6 m
Mass of moon	7.35×10^{22} kg
Mean distance of moon from earth	3.84×10^8 m

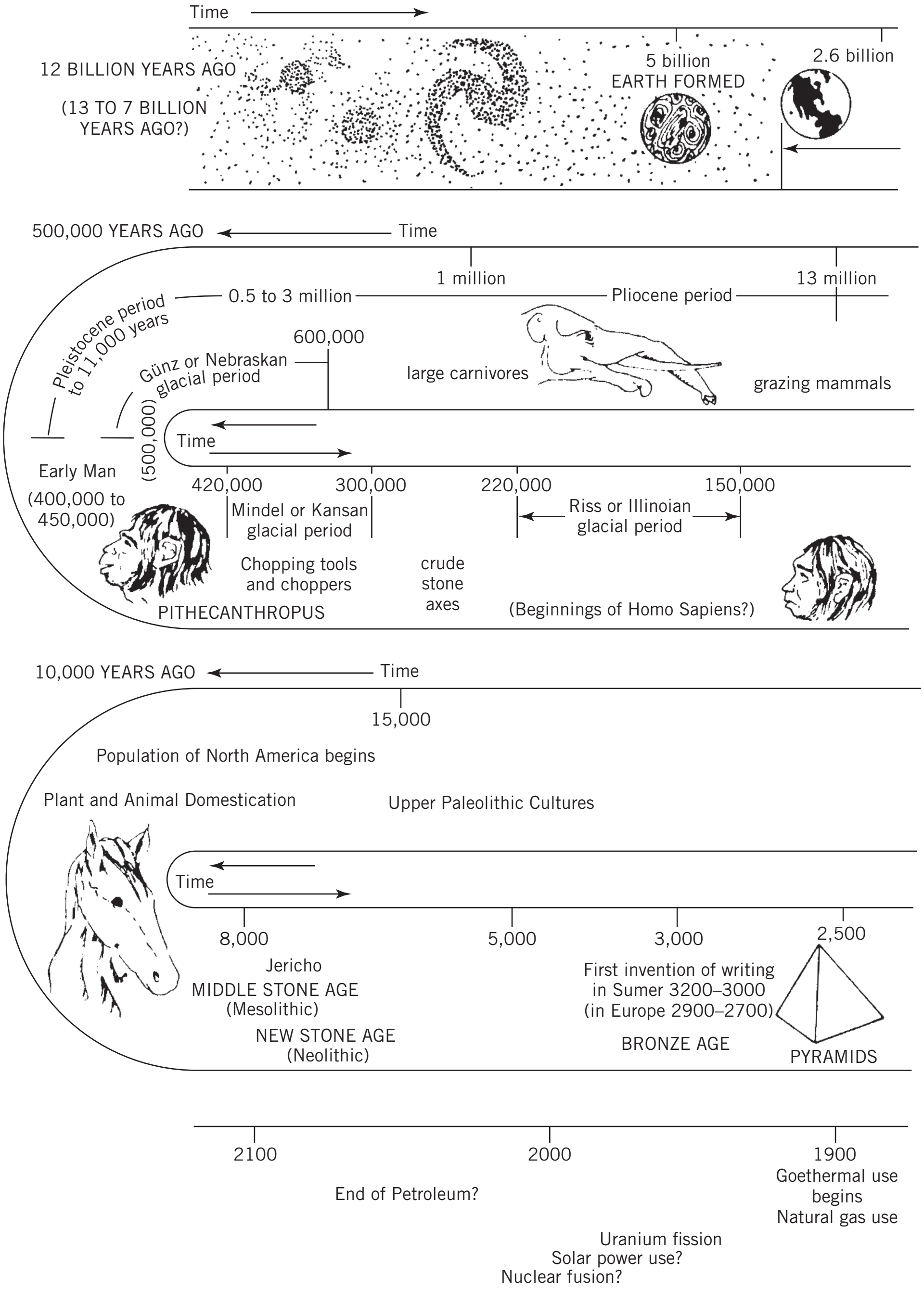
Energy Unit Conversion Factors

		J	kWh	Btu
1 Joule (J)	equals	1	2.78×10^{-7}	9.49×10^{-4}
1 kilowatt hour (kWh)	equals	3.60×10^{6}	1	3413
1 calorie (cal)	equals	4.184	1.16×10^{-6}	3.97×10^{-3}
1 British thermal unit (Btu)	equals	1055	2.93×10^{-4}	1
1 foot-pound (ft · lb)	equals	1.36	3.78×10^{-7}	1.29×10^{-3}
1 electron-volt (eV)	equals	1.60×10^{-19}	4.45×10^{-26}	1.52×10^{-22}

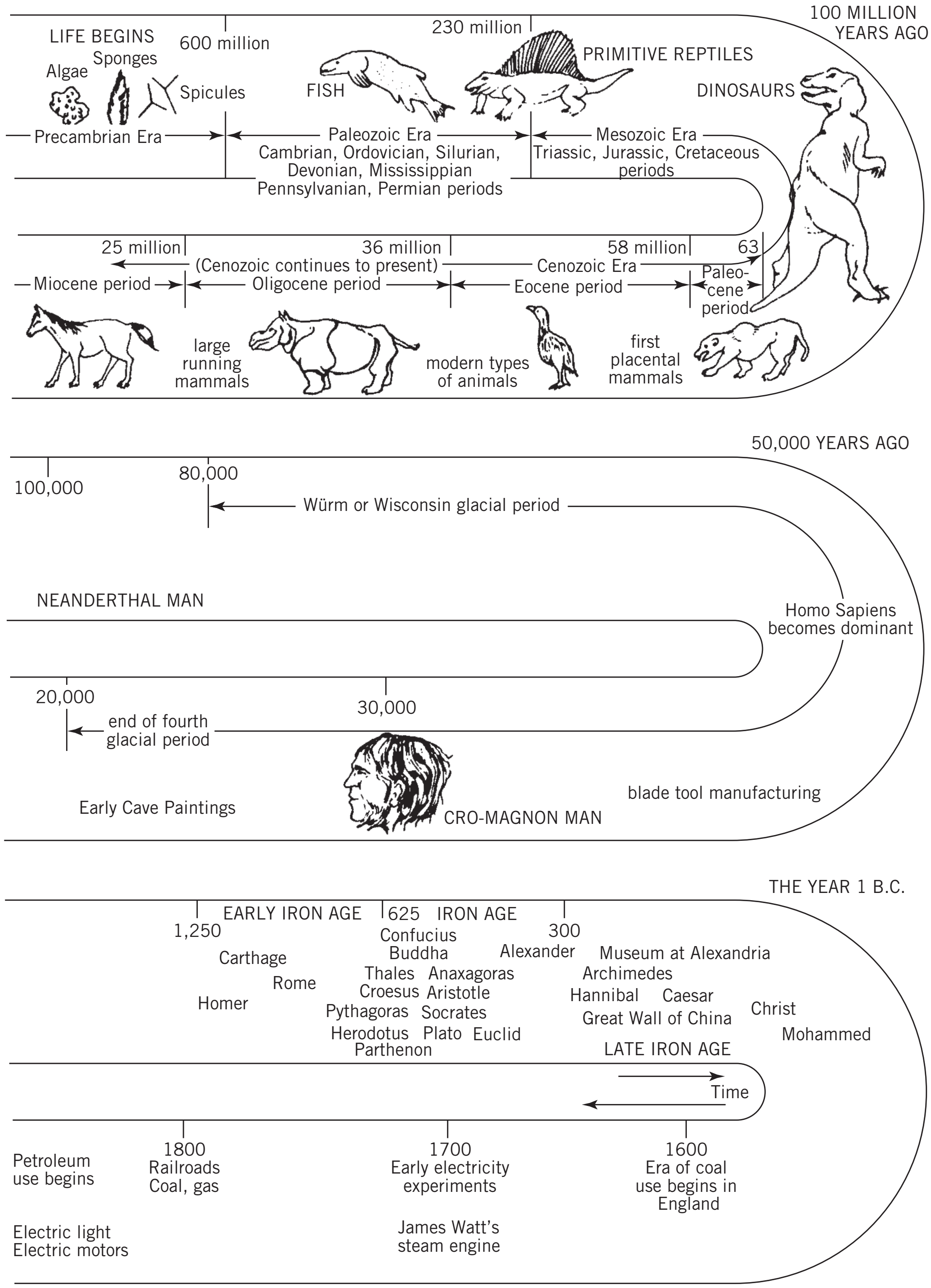
Energy Equivalents

	J	kWh	Btu
Crude petroleum (42 gallon barrel)	6.12×10^{9}	1700	5.80×10^{6}
Bituminous coal (1 ton[a])	2.81×10^{10}	7800	2.66×10^{7}
Natural gas (1000 cubic feet[b])	1.09×10^{9}	303	1.035×10^{6}
Gasoline (1 gallon[c])	1.32×10^{8}	36.6	1.25×10^{5}
Uranium-235 (1 gram)	8.28×10^{10}	2.30×10^{4}	7.84×10^{7}
Deuterium (1 gram)	2.38×10^{11}	6.60×10^{4}	2.25×10^{8}

[a]1 ton = 2000 lb = 0.907 tonne.
[b]At STP.
[c]The U.S. gallon is used in this text. The Imperial gallon used in Canada and Great Britain equals 1.201 U.S. gallons



Representation of the vast difference in time between our rapid use of fossil fuels and their early formation. Adapted from Wilson and Jones, *Energy, Ecology, and the Environment*, copyright © 1974, Academic Press, New York. Reprinted by permission.


100 MILLION YEARS AGO
LIFE BEGINS
600 million
230 million
Algae
Sponges
Spicules
FISH
PRIMITIVE REPTILES
DINOSAURS
Precambrian Era
Paleozoic Era
Cambrian, Ordovician, Silurian, Devonian, Mississippian Pennsylvanian, Permian periods
Mesozoic Era
Triassic, Jurassic, Cretaceous periods
25 million
36 million
58 million
63
(Cenozoic continues to present)
Cenozoic Era
Miocene period
Oligocene period
Eocene period
Paleo-cene period
large running mammals
modern types of animals
first placental mammals
50,000 YEARS AGO
100,000
80,000
Würm or Wisconsin glacial period
NEANDERTHAL MAN
Homo Sapiens becomes dominant
20,000
30,000
end of fourth glacial period
Early Cave Paintings
CRO-MAGNON MAN
blade tool manufacturing
THE YEAR 1 B.C.
1,250
EARLY IRON AGE
625
IRON AGE
300
Carthage
Rome
Homer
Confucius
Buddha
Thales
Anaxagoras
Croesus
Aristotle
Pythagoras
Socrates
Herodotus
Plato
Euclid
Parthenon
Alexander
Museum at Alexandria
Archimedes
Hannibal
Caesar
Great Wall of China
Christ
Mohammed
LATE IRON AGE
Time
1800
Railroads
Coal, gas
1700
Early electricity experiments
1600
Era of coal use begins in England
Petroleum use begins
James Watt's steam engine
Electric light
Electric motors

Energy and the Environment

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This book was set in 10/12 Times TenLT Std Roman by SPi Global and printed and bound by Lightning Source Inc.

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ISBN: 978-1-119-23958-1 (PBK)
ISBN: 978-1-119-22315-3 (EVALC)

Library of Congress Cataloging-in-Publication Data

Names: Ristinen, Robert A. | Kraushaar, Jack J. | Brack, Jeffrey T.
Title: Energy and the environment.
Description: 3rd edition / Robert A. Ristinen, University of Colorado – Boulder, Jack J. Kraushaar, University of Colorado – Boulder, Jeffrey T. Brack, Colorado State University – Fort Collins. | Hoboken, NJ : John Wiley & Sons, Inc., [2016] | Includes bibliographical references and index.
Identifiers: LCCN 2015039880 (print) | LCCN 2015045404 (ebook) | ISBN 9781119239581 (pbk.) | ISBN 9781119179245 (pdf) | ISBN 9781119179238 (epub)
Subjects: LCSH: Power resources – United States. | Pollution – United States.
Classification: LCC TJ163.25.U6 R57 2016 (print) | LCC TJ163.25.U6 (ebook) | DDC 333.79 – dc23
LC record available at http://lccn.loc.gov/2015039880

Printing identification and country of origin will either be included on this page and/or the end of the book. In addition, if the ISBN on this page and the back cover do not match, the ISBN on the back cover should be considered the correct ISBN.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

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PREFACE

In the year 1973, the term "energy" became common in households throughout the United States. At that time, an energy crisis suddenly fell upon the country and for some time it was not unusual for motorists to spend hours waiting in line to obtain gasoline at a filling station. Customers were sometimes limited to a 5-gallon purchase. The speed limit on all highways throughout the nation was reduced to 55 miles per hour, and it stayed that way for 15 years. Decorative lighting was markedly reduced during the holiday season as an energy-saving measure.

The experience of 1973 gave immediate significance to energy for a wide audience. Much has happened since that energy crisis. Gasoline is now widely available, as is electrical energy. However, the problems of energy are complex and go far beyond questions of the immediate availability of motor fuel. These issues affect the entire world and the problems are becoming more severe with the passage of time. While technological advances have vastly increased our reserves of fossil fuel, scientists now overwhelmingly agree that the majority of those reserves must remain in the ground if we are to preserve our environment, even as the citizens of developing countries aspire to share more fully in the use of the world's energy resources.

The topics of energy and the environment are obviously crucial to all of us, and effective policies at all levels of government depend on an informed citizenry. To address this need, courses dealing with the subject are being increasingly offered at colleges and universities in the United States and elsewhere. *Energy and the Environment* was created from experience the authors have had in teaching such courses starting more than 40 years ago at the University of Colorado in Boulder.

The field is changing rapidly, and the step from one decade to the next can be a long one. We continually see new developments in every aspect, from fossil fuels to alternatives, from hydrogen to hybrids. Our major environmental problem, climate change, has become an issue of broad concern, and there are now serious efforts to seek means of mitigation. In this third edition we have included recent statistical information on fossil fuel reserves and consumption as well as new data on atmospheric carbon dioxide and climate change.

Energy and the Environment deals with the core subjects of energy and the environment. With respect to energy, we have tried to cover the basic concepts, resources, applications, and problems of current interest. With respect to the environment, we have included most of the major concerns; unfortunately, because of space limitations, we have had to omit some areas such as water resources and pollution. When the problems covered in this book are examined together, it is seen that many, but not all, of our environmental problems have their origin in our quest for abundant and inexpensive energy.

The web-based material now available on this field is voluminous. With cautious judgment on the part of the reader, these sites can provide abundant, authoritative, and up-to-date information. We have made frequent use of numerous websites, including those of the United States Energy Information Administration, The World Energy Council, The Oak Ridge National Laboratory, and many others, which we have tried to cite when information from those sites is used. In addition, at the end of each chapter we have added many new web-based references to some that have been carried over from the previous editions.

Energy and the Environment is intended for students having little or no background in science or mathematics. Some elementary calculations are included in the subject matter, but these calculations do not involve mathematics beyond introductory algebra, and this is introduced along with the material under discussion.

In this third edition we recognize that many of the troubling issues that have been so apparent for more than 40 years continue on their course. We continue to face the problems associated with fossil fuel combustion, a threat of nuclear weapons proliferation, no politically acceptable means of nuclear waste disposal, changing global climate with no global approach to a solution, burgeoning human population, and so forth. However, encouraging developments are appearing in the areas of renewable energy, energy conservation, and energy-efficient transportation as well as in several other areas.

To extend a comment put forth by Aldo Leopold many years ago, it is our hope that this text will help to bring its readers beyond thinking that "heat comes from the furnace, food comes from the store, water comes from the faucet, gasoline comes from the filling station, truth comes from the experts."

Many of the words above and in the following text were written by our colleague, friend and co-author Jack Kraushaar, who passed away in 2013 during the preparation of this third edition. His insights and enthusiasm, and his contributions to the material presented here, are largely responsible for the development of this series of textbooks.

Acknowledgments

Many people were of great help as we sought to obtain and organize material for the first edition of this text. In particular we thank Dr. Robert Cohen for providing material on ocean energy, especially the subject of OTEC. The Colorado State Department of Health provided valuable information on air quality and pollution control measures. The National Center for Atmospheric Research made available useful information on global warming. In addition, Stacy Davis of Oak Ridge National Laboratory was helpful in providing data on transportation energy matters. Thomas Boden of Oak Ridge National Laboratory helped us obtain data on atmospheric carbon dioxide. We are grateful for this assistance.

In addition to the many people who provided help for the first edition, preparation of the second edition was assisted greatly by many others. In particular, we wish to thank Dr. J. Herring of the National Center for Atmospheric Research and Dr. D. Murphy of the National Oceanic and Atmospheric Administration for technical information on global warming. We also thank Professor Kim Griest of the University of California, San Diego, for his helpful comments on several areas, Dr. Matthew Kohler for going over the entire text, John Katers, of the the University of Wisconsin-Green Bay, who reviewed the accuracy of the manuscript, and Richard Monson of the University of Colorado Facilities Management Department who provided information on the CU cogeneration system.

Nearly all of the material provided for earlier editions by those acknowledged above remains in this third edition, forming the basis for the updates here. Without their input, much of the historical perspective would be lacking from this discussion, and we're thankful for their early contributions. In addition, we'd like to thank David R. Simpson of Bloomsburg University, Vasudeva Rao Aravind of Clarion University, John Katers of the University of Wisconsin at Green Bay, and Nathan Israeloff of Northeastern University, for evaluating early drafts of chapters at the proposal stage and providing useful input. Finally, we thank the staff at Wiley, particularly Production Editor Linda Christina who's attention to detail improved our work in many places, and Nicole Urban who provided invaluable guidance through the long process.

Robert A. Ristinen
Jack J. Kraushaar
Jeffrey T. Brack

CHAPTER 1

Energy Fundamentals, Energy Use in an Industrial Society

Jetta Productions/Media Bakery

1.1 Introduction

Energy enters our everyday lives in many different ways. The energy in the food we eat maintains our body temperature and lets us walk, talk, lift things, and toss frisbees. The use of energy in food has been essential for the existence of all humankind and animals throughout our evolution on this planet. In some developing countries the supplying of food for energy and nutrition is a difficult task that requires most of the waking hours of the population. Food acquisition is just as essential in the more developed countries, but because of the greater mechanization of agricultural production, the effort of only a relatively small number of persons is devoted to obtaining food. This leaves most of the rest of us free to pursue other activities throughout our lives.

Energy in forms other than food is also essential for the functioning of a technical society. For example, in the United States, many times more energy in the form of engine fuel goes into the agricultural enterprise than is obtained in the useful food Calorie content of the food produced. Prodigious amounts of energy are also used to power automobiles, heat homes, manufacture products, generate electricity, and perform various other tasks. In order for our society to function in its present patterns, vast amounts of coal, natural gas, and oil are extracted from the earth and burned to provide this energy. To a lesser extent we also derive energy from hydroelectric plants, nuclear reactors, electric wind generators, and geothermal plants, and, of course, we all benefit enormously from the energy obtained directly from the sun.

The fossil fuels: coal, natural gas, and oil, supply about 82% of the energy used in the United States. These resources evolved hundreds of millions of years ago as plant and animal matter decomposed and was converted under conditions of high temperature and pressure under the earth's surface into the hydrocarbon compounds that we now call fossil fuels. Since the beginning of the machine age, industrial societies have become increasingly dependent on fossil fuels. A hundred and fifty years ago, the muscular effort of humans and animals played an important role in the American economy, and firewood supplied most of the heat energy. Now only a small fraction of our energy comes from firewood and we rely much less on the physical effort of people and animals. The process by which we have moved to our present dependence on coal, oil, and natural gas is illustrated in Figure 1.1, where the energy consumed in the United States each year from various sources is shown in terms of quadrillion British thermal units (QBtu) for the years 1850 to 2003. The definition of QBtu will be given in Section 1.6.

Should we be concerned that so much of our energy is now coming from fossil fuels? Here are two of many factors that should cause concern.

First, the fossil fuel resource is limited in amount. The fossil fuels were produced by solar energy hundreds of millions of years ago, and when they are gone, there will be no more. It is true that the fuels are still being formed, but at an entirely negligible rate compared to the rate at which we are consuming them. We first began consuming the fossil fuels at an appreciable rate only about 150 years ago. How long will they last? On a global scale we will still have some coal for a few centuries, but natural gas and oil will be in short supply more quickly. In the United States, the situation is worse than the global average because we are depleting our resources at a faster rate than in other fossil fuel-rich areas around the globe. Figure 1.2 shows the narrow blip of our fossil fuel use set against a time scale of thousands of years. As you consider the brief duration of this blip, remember that we have living trees thousands of years old, a much longer time than what will be spanned by the entire era of fossil fuel consumption. It is clear from this figure that we live in an extraordinary time in the many billion year history of the earth. The entire stock of fossil fuels available for our use has been held in storage under the earth's surface for more than a hundred million years, and now it is being completely exploited in only a few centuries.

Second, unintended environmental consequences result from the extensive scale of our use of the fossil fuels for everything from heating our homes to powering our automobiles. When we burn coal, natural gas, or oil to obtain energy, gaseous compounds are formed and dumped into the atmosphere. This is causing problems we are just beginning to face. For many years it was felt that the emitted gases were not significant, given the vastness of the earth's atmosphere. But now with increasing world population,

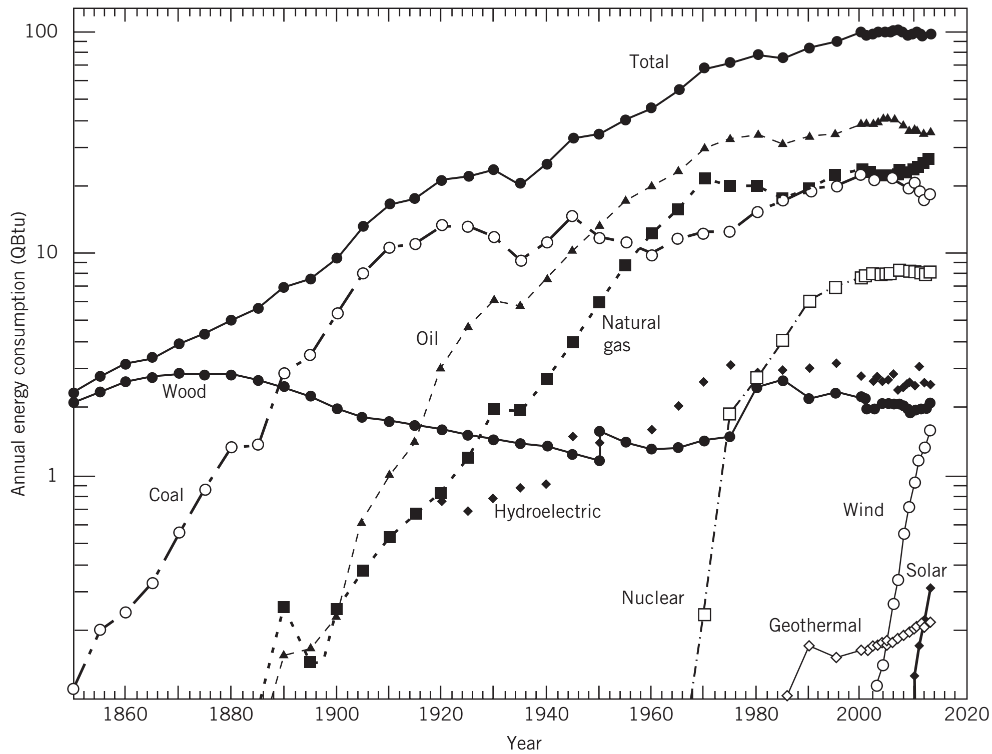

Figure 1.1 Various forms of energy consumed in the United States since 1850. This type of graph is called a semilogarithmic plot, an explanation of the scales is given in the Appendix. *Sources: Historical Statistics of the United States*, *Colonial Times to 1970*, U.S. Department of Commerce. Bureau of the Census, 1975; U.S. Energy Information Administration, *Annual Energy Review*, 2014. The wood data set from 1850 to 1950 is from the first source. The wood data set from 1950 to 2013 is from the second source; it includes wood, black liquor (a byproduct of the wood-based paper production process), and wood waste.

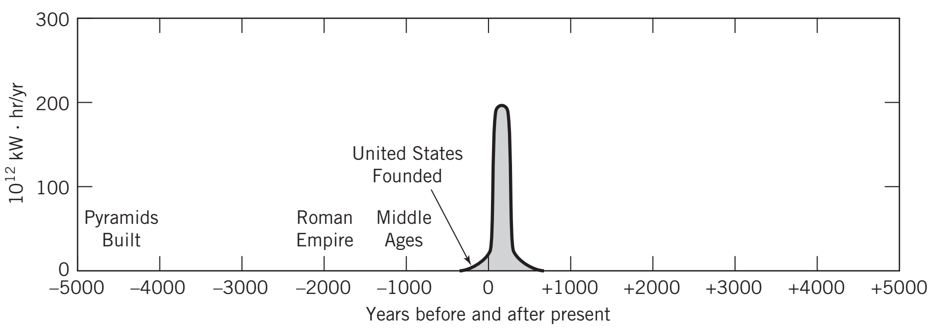

Figure 1.2 The complete exploitation of the world's fossil fuels will span only a relatively brief time in the 10,000 year period shown centered around the present. (*Source*: Reprinted with permission from M. K. Hubbert, *Resources and Man*, Washington, D.C., National Academy of Sciences, 1969. Historical events added.)

and industrialization, this is no longer true. The atmospheric pollution is producing health problems and even death, and it is now becoming recognized that carbon dioxide emissions are threatening to produce climate changes over the entire globe.

Can we find solutions to these problems of resource depletion and environmental pollution? Clearly the answers are not simple or the solutions would have been put into effect by now. The subject is complex and involves some understanding of topics such as patterns of resource depletion, the workings of heat engines, solar cells, wind generators, nuclear reactors, and a myriad of other specialized subjects. We do not have to become experts on each of these individual topics to be sufficiently well informed as voting citizens to influence a rational decision-making process. Our goal is to gain understanding concerning the essential points.

1.2 Why Do We Use So Much Energy?

A partial answer to this question is simple—we don't use our energy resources as efficiently as we could. The standard of living we enjoy in the United States could be maintained with an expenditure of far less energy per person than at present. This side of solving the energy problem will be explored later under the heading of Energy Conservation. There is a large discrepancy between the rate of energy use by a typical citizen of an industrialized society and the typical citizen of a developing country, and it is accompanied by a notable difference in what we perceive as the standard of living. This is illustrated in Figure 1.3, where we see the per capita Gross Domestic Product (GDP) and the per capita energy use for several countries of the world. Although not indicated on this figure, several developing

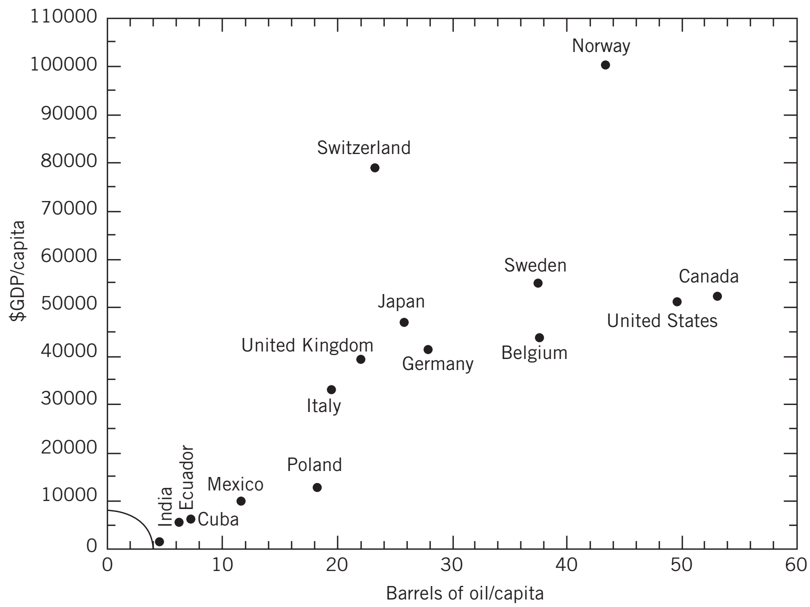

Figure 1.3 The Gross Domestic Product (GDP) per capita in U.S. dollars is compared to the total energy consumed per capita in equivalent barrels of oil for several countries. The small quarter-circle at the lower left corner is discussed in the text. (*Source*: *United Nations Statistical Yearbook*; data January 2012.)

countries have very low rankings by either measure, and they would be located within the small quarter-circle shown at the extreme lower left corner of the figure.

There is no essential relationship between GDP per capita and the standard of living, but both are often related to the use of energy. A citizen of a developing country might use the energy equivalent of less than one barrel of oil per year, compared to an annual energy equivalent of 20 to 60 barrels per capita for the most industrialized countries. The nonindustrialized countries derive a large fraction of their necessary energy from the muscular effort of people and animals. There is an interesting quotation from an early physics textbook written by J. Dorman Steele in 1878:

> *The combustion of a single pound of coal, supposing it to take place in a minute, is equivalent to the work of three hundred horses; and the force set free in the burning of 300 pounds of coal is equivalent to the work of an able-bodied man for a lifetime.*

This observation, while a bit off the mark in exact technical detail, is essentially correct, and it sets the stage and justifies the enormous effort that has gone into our learning to exploit the fossil fuels—energy reserves held in waiting for hundreds of millions of years—until we have learned to use them with high efficiency to ease human labor. Whether we refer to tons of coal or barrels of oil, it is indeed the fossil fuels that have had the major effect. Without fossil fuels we surely would have made progress toward labor-saving technology based on waterpower, firewood, windpower, and perhaps even nuclear power, but we would not have gone nearly so far in developing the energy-intensive society in which we now live.

We may take the average power available to a person to be a measure of the productive output of a society. As seen in Figure 1.4, in the United States in 1850, about 0.38 horsepower per person was available, of which 0.26 horsepower was provided by work animals. We now have a few hundred times that from other sources. Most of the difference is due to our use of fossil fuels to make the wheels go around.

Example 1.1

Using generally available information, estimate the dollar value of the equivalent amount of oil which we each use annually.

Solution

Given:

53 barrel/(yr · person); see Figure 1.7.
42 gallons/barrel; see Energy Equivalents chart inside front cover.
Oil is approximately $1.25/gallon; estimated from reported crude oil prices.

$$53\ \frac{\text{bbl}}{(\text{yr}\cdot\text{person})} \times 42\ \frac{\text{gal}}{\text{bbl}} \times 1.25\ \frac{\$}{\text{gal}} = \mathbf{2782}\ \frac{\mathbf{\$}}{(\mathbf{yr}\cdot\mathbf{person})}$$

Note that the units of bbl and gal cancel in this calculation. We can extend the answer to obtain the cost per day of this oil.

$$2782\ \frac{\$}{(\text{yr}\cdot\text{person})} \times \frac{1\ \text{yr}}{365\ \text{day}} = \mathbf{7.62}\ \frac{\mathbf{\$}}{(\mathbf{day}\cdot\mathbf{person})}$$

Here the units of yr have canceled.

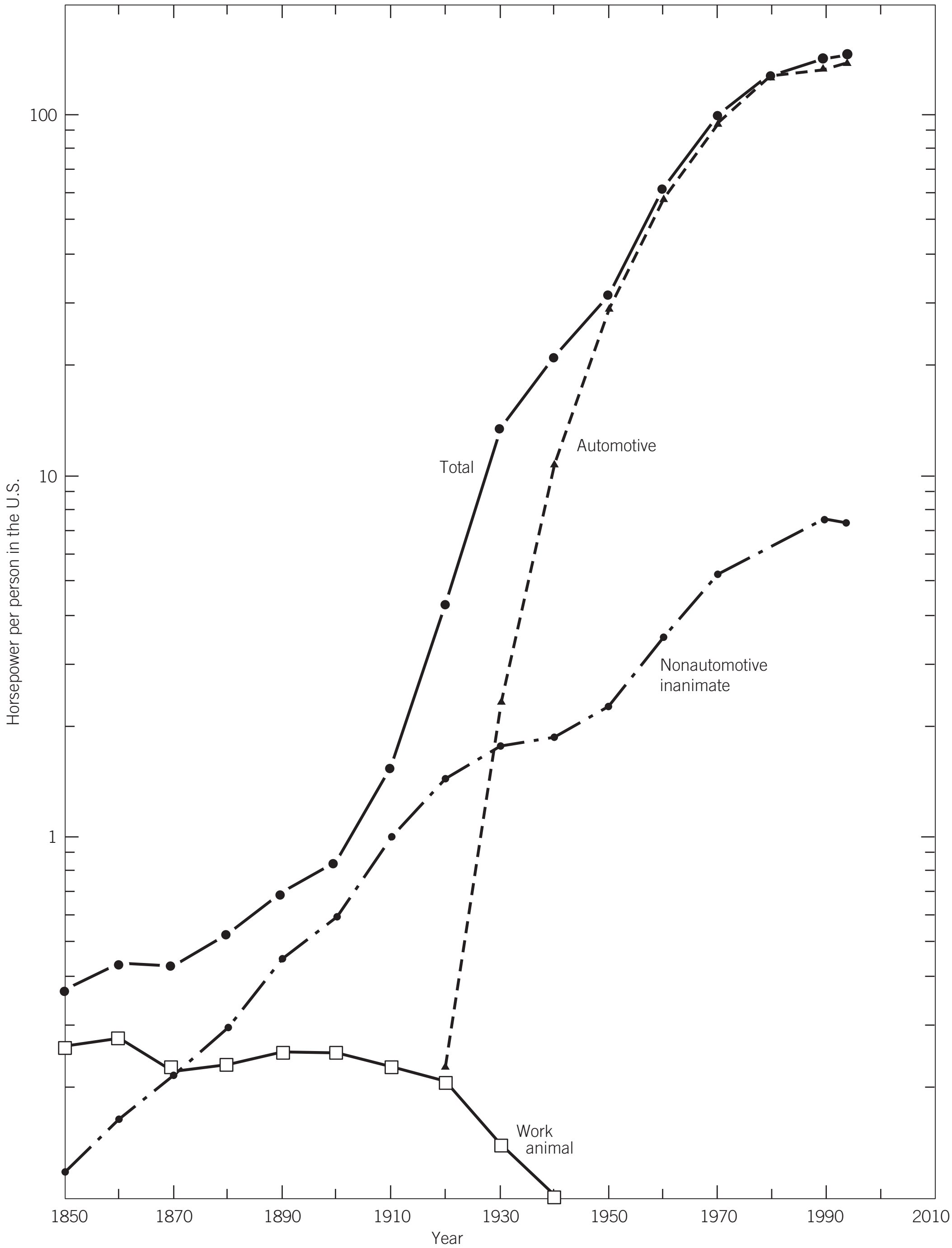

Figure 1.4 Horsepower per capita of all prime movers in the United States since 1850. Only a small fraction of this available horsepower is in use at any given time. (*Source*: *Historical Statistics of the United States*, *Colonial Times to 1970; Statistical Abstracts of the United States* 2003. Washington, D.C.: U.S. Department of Commerce, Bureau of the Census.)

1.3 Energy Basics

1.3.1 General

Our discussions of energy use and resources can proceed effectively only if we have a common understanding of exactly what energy is, and what forms it can take.

Physicists and engineers define energy as *the capacity to do work*, leaving us then with the need to define *work*. Work is a general term to most of us; it signifies everything from shoveling snow off the driveway to making out an income tax form, studying for an examination, or writing an essay. But we may not think of taking a bicycle ride on a nice Saturday afternoon as being work; it's too pleasant an experience. In order to make work a useful concept for scientific purposes, we must forget about the pleasant and unpleasant aspects and come up with a definition suitable for quantitative analysis. We can achieve this by defining work to be the product of force times the distance through which the force acts. A common example of this definition of work is given by a force pushing an object along a rough surface. The force could be exerted by any agent: human, steam engine, sled dog, or electric motor. In the British system of units, the force is given in pounds (lb) and the distance in feet (ft), so work will then be in units of pound-feet, or more commonly foot-pounds (ft·lb). In the metric system, work has the units of newton-meter (N·m), where the newton is the metric unit of force and the meter is the metric unit of distance. The metric unit of energy, the joule, is defined as 1 J = 1 N·m. The two systems of units (British and metric) are both in common use in the United States, and conversions between them are not difficult. The numerical conversion factors are given inside the covers of this book. It is important to note that the same units are used for energy and work. We will often find that energy and work are equivalent; the units are identical and, in many cases, the work done on an object is equal to the energy gained by the object. A more complete discussion of energy units is given in Section 1.4 of this chapter.

In the example given above, the work, equal to the product of force times distance, comes out to be zero if the pushed object doesn't move through some distance. A person can push against a solid wall all day long, but if the wall doesn't move, no work is done, even though the experience will be tiring to the person doing the pushing. In another case, the work being done also comes out to be zero if an object moves through a distance but with no force being exerted on it in the direction of the motion. A hockey puck sliding freely along a perfectly slippery ice surface represents a situation where no work is being done on either the puck or the ice, and no energy is being expended. Both the force and the distance must have nonzero values if work is to be done.

Here's an example that will help us gain a feeling for magnitudes and units of work and energy: Imagine that you slowly lift a 10 pound sack of sugar upward 1 foot. The force is 10 pounds and the distance is 1 foot, so the work (force times distance) you do on the sack of sugar is 10 ft·lb. The energy to do this work would have come from the food you ate. The work done can also be expressed in metric units. From the chart of conversion factors, we see that 1 ft·lb is the same as 1.36 joules, so the 10 ft·lb is 13.6 joules. Or we could deal in terms of British thermal units (Btu), another unit of energy. From the chart of conversion factors, 1 ft·lb is seen to equal 0.00129 Btu. Thus the 10 ft·lb of energy expended would be the same as 0.0129 Btu.

Example 1.2

A force of 50 pounds pushes a box along a floor a distance of 100 feet. How much work (in ft·lb) has been done? How much energy (in joules) has been expended?

Solution

$$\begin{aligned}\text{Work} &= \text{force} \times \text{distance}\\ &= 50\ \text{lb} \times 100\ \text{ft} = \mathbf{5000\ ft \cdot lb}\\ \text{Energy expended} &= \text{work done}\\ &= 5000\ \text{ft}\cdot\text{lb} \times 1.36\ \frac{\text{joule}}{\text{ft}\cdot\text{lb}} = \mathbf{6800\ joules}\end{aligned}$$

The conversion factor between ft·lb and joule has been taken from the table of conversion factors.

1.3.2 Forms of Energy

Energy comes in many forms and can in principle be transformed from one form to another without loss. This is consistent with the Principle of Energy Conservation, which we will address later in Section 1.7. Some of the common forms of energy are discussed here.

(a) Chemical Energy Chemical energy is the energy stored in certain chemicals or materials that can be released by chemical reactions, often combustion. The burning of wood, paper, coal, natural gas, or oil releases chemically stored energy in the form of heat energy and, as discussed earlier, most of the energy used in the United States is of this form. We heat our homes, power our automobiles, and turn the generators that provide electricity primarily with chemical energy.

Other examples of chemical energy sources are hydrogen, charged electric batteries, and food in the stomach. Chemical reactions release this energy for our use.

(b) Heat Energy Heat energy is the energy associated with random molecular motions within any medium. The term thermal energy is interchangeable with heat energy. Heat energy is related to the concept of temperature. Increases of heat energy contained in any substance result in a temperature increase and, conversely, a decrease of heat energy produces a decrease of temperature.

(c) Mass Energy Albert Einstein taught us that there is an equivalence between mass and energy. Energy can be converted to mass, and mass can be converted to energy. The famous formula

$$E = mc^2$$

gives the amount of energy, E, represented by a mass, m. This energy is often referred to as the *mass energy*. The symbol c stands for the speed of light.

The most dramatic recent examples of this equivalence are in nuclear weapons and nuclear reactors, but our entire existence is now known to depend on nuclear reactions in the sun. There we have atomic nuclei coming together in a reaction with the resulting products having less mass than what went into the reaction. The mass that is lost in the reaction appears as energy according to the Einstein equation

$$\Delta E = \Delta mc^2,$$

where Δm (read it as *delta m*) is the missing mass, and c is the speed of light. The energy that appears, ΔE, is in joules if Δm is in kilograms and c is in meters per second. Because c is such a very large number, 3×10^8 m/sec, a small loss of mass results in a huge release of energy. At a detailed level, any reaction, of any type, chemical or nuclear, which releases energy does so in association with a loss of mass between the inputs and outputs, according to the Einstein equation.

The idea of mass energy is relatively new in human experience. Einstein put forth the $E = mc^2$ equation in the early 1900s. It was not until the 1920s and 1930s that the nuclear fusion processes in stars were first understood and in the 1940s that energy release from man-made nuclear fission reactions was first demonstrated.

(d) Kinetic Energy Kinetic energy is a form of mechanical energy. It has to do with mass in motion. An object of mass m, moving in a straight line with velocity v, has kinetic energy given by

$$KE = \frac{1}{2}\, mv^2.$$

If the object in question is an automobile, work must be done to bring the auto up to speed, and, conversely, a speeding car must do work in being brought to rest. The work done on the accelerating car is derived from the fuel, and the work done by the stopping car will appear mainly as heat energy in the brakes if the brakes are used to stop the car.

In a similar manner, an object rotating around an axis has kinetic energy associated with the rotation. It is just a matter of all the mass elements which make up the object each having velocity and kinetic energy according to the description given above. These combined kinetic energies make up the kinetic energy of the rotating object. We commonly see rotational kinetic energy in a potter's wheel, a child's top, an automobile flywheel, and so forth. Someday rapidly rotating flywheels may provide the stored energy needed to power a car.

(e) Potential Energy Potential energy is associated with position in a force field. An obvious example is an object positioned in the gravitational field of the earth. If we hold an object having weight w at a height h above the earth's surface, it will have potential energy

$$PE = w \times h$$

relative to the earth's surface. If we then release the object and let it fall to the earth, it will lose its potential energy but gain kinetic energy in the same amount. Another example would be at a hydroelectric dam where water is effectively, but usually not literally, dropped onto a turbine below. In this example, the water hitting the blades of the turbine has kinetic energy equal to the potential energy it would have had at the top of the reservoir surface. This potential energy is measured relative to the turbine's location. The kinetic energy of the water becomes electric energy as the turbine spins a generator.

(f) Electric Energy The idea of electric energy is less obvious than the examples of other types given previously. Not surprisingly, electric energy is one of the last types of energy to have been brought into practical use. With electric energy, nothing can be seen, either stationary or in motion, but the effects can be readily apparent. In spite of this difficulty, an understanding of electric energy is necessary for the functioning of a complex industrial society. It is electric energy that allows us to have telephones, television, lighting, air-conditioning, electric motors, and so forth.

If an electric charge q is taken to a higher electric potential (higher voltage) V, then it is capable of releasing its potential energy, given by $PE = q \times V$, in some other form such