

Its Use and
the Environment

Energy

FIFTH EDITION

The cover features a photograph of a landscape at sunset. In the foreground, a row of solar panels is visible, angled towards the right. In the background, several wind turbines are silhouetted against a sky with warm, orange and yellow hues. The overall scene is dark, with the sunset providing the primary light source.

Hinrichs • Kleinbach

Useful Websites

Because the science, technology, economics, and political atmosphere associated with the subject of energy are constantly changing, the Internet is a good source of current information. The ability of the Internet to constantly update its information makes it a valuable resource for locating up-to-date facts and figures as well as to receive information on new advancements and discoveries.

The website that accompanies this book contains a series of links to sites with content that can further help you understand the material presented in each chapter. The links are available at www.cengagebrain.com/shop/ISBN/9781111990831.

You can often locate useful and supplementary information through typical search engines like Google or Bing. The following list of standard sites can provide information on energy matters that you may find useful. The content is usually obvious from the name of the site. Most of these sites contain links to other sites—some have good educational materials and some will put you on useful email lists. Enjoy.

eia.doe.gov	Energy Information Administration—official energy statistics from the United States government
eere.energy.gov	Energy efficiency and renewable energy information from the United States Department of Energy
epa.gov	United States Environmental Protection Agency
wri.org	World Resources Institute
iea.org	International Energy Agency
ashrae.org	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
api.org	American Petroleum Institute
gasandoil.com	Portal site for gas and oil industry information
repp.org	Renewable Energy Policy Project and the Center for Renewable Energy and Sustainable Technology
aceee.org	American Council for an Energy-Efficient Economy
awea.org	American Wind Energy Association
ases.org	American Solar Energy Society
evworld.com	Electric vehicles information with a weekly email newsletter
worldwatch.org	Worldwatch Institute—publisher of State of the World annuals
eande.lbl.gov	Environmental Energy Technologies division of Lawrence Berkeley National Laboratory
fsec.ucf.edu	Florida Solar Energy Center at the University of Central Florida
nrc.gov	United States Nuclear Regulatory Commission
new.ans.org	American Nuclear Society
ucsusa.org	Union of Concerned Scientists
nrel.gov	National Renewable Energy Laboratory

Energy

Its Use and the Environment

Fifth Edition

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Preface



Introduction to the Fifth Edition

Energy, Its Use and the Environment, is an introductory textbook that emphasizes the physical principles behind energy, its uses, and its effects on our environment. It can be used in physics, technology, physical science, and environmental science courses for nonscience majors. No math or other science prerequisite is necessary. Much of the pedagogy used herein comes from a one-semester general education course one of us (R.H.) has taught at State University of New York, College at Oswego, over the past 25 years. Both of us have been involved in conducting energy education workshops for New York State secondary school science and technology teachers for more than 25 years.

For this fifth edition, all the data on energy resources, energy use, and energy technologies have been updated. Since the fourth edition (only seven years ago), we have seen oil prices reaching all-time highs and a rapid growth in energy use by China and India. Concern over the large dependence of the U.S. transportation sector upon imported oil continues to grow. Will the peak in worldwide oil production be upon us soon? An economy based upon hydrogen and fuel cells seems closer, but there are many bumps in the road. Electric vehicles are starting to make small but substantial inroads into the marketplace. The world is also seeing an increasing interest in renewable energy. The use of wind energy grows at a rate of about 30% per year, yet renewables today only account for about 7% of the United States' energy supply, and about 14% of the world's total energy use. These trends are examined throughout the book. We continue to emphasize the environmental impact of fossil-fuel consumption, in part by putting chapters on fossil-fuel use, air pollution, and global warming material early in the text. Due to environmental concerns about global warming, extra material has been added. The possible rebirth of nuclear power is discussed in later chapters in light of the Japanese earthquake/tsunami catastrophe. The interdependence of the world economies and environments, especially when it comes to energy, have led us to add more examples dealing with energy use in other countries, both industrialized and developing. We include a "How Would You Choose?" question at the beginning of every chapter that will prompt the readers to examine their own opinions on a particular energy-related issue. This question is revisited at the end of the chapter and the reader is asked whether material learned in that chapter has changed their position on this issue.

Goals of This Book

Because the subject of energy is multifaceted, this book has several purposes. First and foremost, it seeks to explain the basic physical principles behind the different energy transformations that occur, including the study of mechanics, electricity and magnetism, thermodynamics, and atomic and nuclear physics. At the same time, the text covers crucial environmental questions arising from energy use that currently are receiving much public attention, such as global warming, radioactive waste, and municipal solid waste. The best way to understand the consequences of present and future energy alternatives, and the environmental, social, and economic tradeoffs that must be made, is to understand the scientific principles involved. These principles are presented with a minimal amount of math and with the help of everyday examples. Each chapter has a set of problems (mainly nonmathematical) that seeks to emphasize the basic principles and apply them to situations dealing with energy and the environment. Many of the standard topics found in introductory physics textbooks are included. As a consequence, this book can be used as the text in a conceptual physics or physical science course with energy as the central theme, as has been our practice.

Second, the book examines different aspects of each energy resource, including the principles involved and the environmental and economic consequences of its use. Renewable energy is treated early on, after heat transfer, and eventually everything from solar heating systems to photovoltaic devices to wind-turbine generators is covered. The principles of nuclear power and the debate over radioactive waste disposal are covered in depth. At the heart of most energy conversion schemes is the heat engine, so general principles in this area are developed early (Chapter 4). The environmental aspects of generating electricity and using it are also an underlying theme. Air pollution and global warming are treated early on, in separate chapters, as are some ways in which their impacts can be lessened.

Third, the textbook seeks to integrate the complex questions of energy policy and possible energy strategies. There are no simple answers or single alternatives that can provide all of our energy needs, preserve our economic prosperity, and protect our environment. As a consequence, questions (many unanswered) are brought up throughout the book to cause readers to critically think ahead and maybe even begin to develop their own solutions. The “How Would You Choose?” questions at the beginning of every chapter further encourage a critical approach. The important theme of energy conservation is emphasized with examples *throughout* the textbook, rather than in a separate chapter, because the efficient use of energy should be of utmost concern in every area—from energy mechanics to heat transfer to electricity use. Practical suggestions are given that we hope will cause the readers to evaluate their individual roles in using energy more effectively.

Many books have an energy theme, but few seek both to teach general physical principles and to cover the many alternatives of energy supply and conservation. These themes are presented in such a way that they will appeal to the growing audience of non-science majors, as well as provide information relevant to those interested in science and engineering careers.

Coverage

Although the material in this textbook is organized to follow a somewhat traditional sequence presented in a physics course, we have tried to order the topics in a way that touches the current interests of students. Solar heating is covered early (Chapter 6), but only after concepts of heat transfer (Chapter 4) and residential energy conservation (Chapter 5) have been discussed. Chapters 8 and 9 deal with the environmental aspects of energy use, namely air pollution (from both stationary and mobile sources), global warming, and thermal pollution. These topics follow Chapter 7 on fossil fuels. The physics of oil exploration and recovery is covered in Chapter 7 as a special topic. Photovoltaics and the rapidly growing area of wind energy follow Chapters 10 and 11 on electrical energy production. New automotive technologies incorporating fuel cells and hybrids and electric vehicles are treated within these two chapters. Nuclear fission is covered in Chapter 14, after a chapter on the fundamentals of atomic and nuclear physics. Chapter 17 covers the broad topic of biomass, from wood combustion to municipal solid waste to the production of alcohol fuels from corn.

Features

Many features in this text are designed to encourage students to understand the crucial role of energy in our society and implications stemming from their own consumption of energy. The textbook is designed to make physics and its applications relevant and interesting to nonscience majors. A description of features follows:

- **“How Would You Choose?”** questions start each chapter by describing a real-world situation in which the reader is asked to make a decision that utilizes the concepts in the chapter. The question is revisited at the end of each chapter to examine how applying the science learned in the chapter affects the decision made.
- **Hands-on activities** that students can perform in their home or dorm room with common items. These activities provide opportunities to experimentally reinforce the material covered. These are both integrated into the chapters and placed at their ends. Some examples are the construction of a simple shoebox model to examine solar heating, an experiment to study heat transfer from insulated soda pop cans, an investigation of atmospheric particulates. All of the activities have been tested, many of them in the summer workshops for secondary school science and technology teachers that we direct.
- **Residential use of energy**, which is emphasized through many examples that are relevant to the home. Analysis of heat losses in the home and ways to reduce them are covered in Chapter 5. A home energy audit (developed by the authors) is provided in Appendix C. New energy-efficient lighting fixtures are covered in Chapter 10 on electricity.
- **International perspectives on energy**, which are emphasized throughout the textbook. Although the book primarily focuses on the United States’ use of energy, we are part of an interdependent global village. As we well know, political

events in other parts of the world can have important effects on our own economy. Attention is also focused on those people who live in developing countries, where energy plays a critical role. “Focus on” boxes, which highlight interesting applications or unusual facts about energy, help in this area. Both of us have had a number of years experience working in developing countries (Ethiopia, Kenya, Oman, Qatar, Palestine).



- **CengageBrain** offers a variety of free tools to help students (www.cengagebrain.com/shop/ISBN/9781111990831). Lists of up-to-date Internet reference sites organized by chapter provide current information about this rapidly changing field. Worksheets for the home heating analysis in Appendix C can be downloaded as a PDF file for easy printing. A glossary and flash cards help students to learn the material and prepare for exams.
- **Resources** available to qualifying instructors at the password-protected instructor site www.cengage.com/physics/hinrichs5e include downloadable **electronic files of text art** and a downloadable full **Instructor's Manual**. The expanded Instructor's Manual contains instructor's notes, answers to selected end-of-chapter questions, classroom demonstrations, a bank of test questions, and worksheets for complete mini-labs that can be printed and assigned.

Other features include appendixes that provide current information on energy use in the United States and the world, end-of-chapter summaries, questions and problems, worked examples, and a glossary.

Teaching Options

Because of the many facets of energy use and our environment, some sections and chapters could be deleted without any loss in continuity to produce a shortened course. For example, the section on heat engines in Chapter 4 could be deleted (especially for the non-science major); the Carnot efficiency could be introduced later for that part of Chapter 9 on thermal pollution. For a shorter course, you might wish to skip Chapter 15 on biological effects of radiation and Chapter 16 on fusion, and concentrate instead on biomass conversion in Chapter 17. While Chapters 7 and 8 provide some physics background on fluids and oil exploration technology, they could be skipped if the course wished to reduce coverage of some of the environmental aspects of energy use. The nontechnical style of the writing allows the instructor to assign sections in each chapter as outside reading, making it possible to cover more of the book than could be covered in class discussion alone. The authors have found that the importance of the topic of energy can be made more relevant by having students bring to class local or national newspaper articles dealing with energy for discussion.

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Roger Hinrichs and Merlin Kleinbach
Seattle, Washington and Oswego, New York
October, 2011

Introduction



Chapter

1

- A.** Energy: An Initial Definition
- B.** Energy Use and the Environment
 - Focus on 1.1** Our Earth—Then and Now
- C.** Energy Use Patterns
- D.** Energy Resources
 - Focus on 1.2** Energy Use in China
- E.** Exponential Growth, Peak Oil, and Resource Depletion
- F.** Oil: A Critical Resource
- G.** Energy Conservation
- H.** Economic and Environmental Considerations
- I.** Future Scenarios
 - Focus on 1.3** The Kyoto Protocol on Climate Change

A. Energy: An Initial Definition

Energy is one of the major building blocks of modern society. Energy is needed to create goods from natural resources and to provide many of the services we have come to take for granted. Economic development and improved standards of living are complex processes that share a common denominator: the availability of an adequate and reliable supply of energy. The modernization of the West and the East from rural societies to affluent, urban ones was made possible through the employment of modern technology based on a multitude of scientific advances—all of which are energized by fossil fuels. Political events, beginning with an oil embargo in 1973 and continuing through the Iranian revolution of 1979, the Persian Gulf War of 1991, and the Iraq invasion of 2003, made many people aware of how crucial energy is to the everyday functioning of our society. Long gasoline lines and cold winters with natural gas shortages in the 1970s are still unhappy memories for some people. Despite those unhappy memories, the energy crises of the 1970s were almost forgotten by the 1980s. However, that decade brought an increased awareness of our environment. Concerns about global warming, acid rain, and radioactive waste are still very much with us today, and each of these topics is related to our use of energy.

1

While an interest in being energy self-sufficient and producing one's own power was a strong desire of some in the 1970s and 1980s, during the second half of the 1990s, the entire public began to have another choice—that of being able to select their own provider of electricity. The electric power industry moved away from a traditional, highly regulated industry to one of deregulation and competition. Beginning in 1997, customers were given the chance to shop for their own supplier—and the bottom line (cost) was not the only criterion. Many people decided to buy from the producer who polluted least, so-called “green power” alternatives.

The tragic events of September 11, 2001, changed the world forever. Continuing threats and actions of terrorists have an effect upon energy issues as much as on public safety. The United States (and many other countries of the industrialized and developing world) imports over half of its oil. Many diverse groups are calling for action on this issue because such a large dependence on imported oil poses a risk to our homeland security and our economic well-being. Most of our imported oil goes for transportation, so increased automobile efficiency, alternate fuels, and conservation must be pursued. Changes take time, yet it didn't take long for oil prices to rise by nearly a factor of two, as the year 2008 showed.

Energy pervades all sectors of society—economics, labor, environment, international relations—in addition to our own personal lives—housing, food, health, transportation, recreation, and more. The use of energy resources has relieved us of much drudgery and made our efforts more productive. People once had to depend on their own muscles to provide the energy necessary to do work. Today muscles supply less than 1% of the work done in the industrialized world.

Energy supplies are key limiting factors to economic growth. We have become a very interdependent world, and access to adequate and reliable energy resources is central for economic growth. About 40% of the world's energy comes from oil, much of which is imported by the industrialized nations and much of which comes from the Persian Gulf. From this region, Japan imports 80% of its oil, and the United States imports 18% of its oil. While France imports almost all of its oil, only 15% comes from the Persian Gulf. If industrialized nations encounter any significant restriction to their sources of oil, through either reduced supplies or large price increases, their economies will suffer considerable damage.

Your own picture of energy might be colored in many ways by your experiences. You might think of the “energy” (or the lack of it) that a particular person possesses, or the kinetic energy that a stone gains as it drops, or the energy responsible for the movement of automobiles, or the energy used in the production of heat and light. One dictionary defines energy as the “capacity for vigorous action; inherent power; potential forces.” Energy is found in many forms, and one purpose of this book will be to identify them and study how they can be used. Energy is found in such forms as wind and flowing water, and stored in matter such as fossil fuels—oil, coal, natural gas—where it can be burned for “vigorous action.”

Energy might best be described in terms of what it can do. We cannot “see” energy, only its effects; we cannot make it, only use it; and we cannot destroy it, only waste it (i.e., use it inefficiently). Unlike food and housing, energy is not valued in itself but for what can be done with it.

Energy is not an end in itself. The fundamental goals we should have in mind are a healthy economy and a healthy environment. We have to tailor our energy policy as a means to those ends, not just for this country but in global terms as well.

—Richard Balzhiser, former president of Electric Power Research Institute

Energy is a basic concept in all science and engineering disciplines. As we will discuss in the next chapter, a very important principle is that energy is a conserved quantity; that is, the total amount of energy in the universe is a constant. Energy is not created or destroyed but just converted or redistributed from one form to another, such as from wind energy into electrical energy, or from chemical energy into heat. We will study the various forms of energy—chemical, nuclear, solar, thermal, mechanical, electrical—and the useful work that energy is capable of doing for us. We will explore both energy resources and energy conversion processes.

Understanding energy means understanding energy resources and their limitations, as well as the environmental consequences of their use. Energy, environment, and economic development are closely linked. Over the past three decades, global energy consumption has almost doubled while the United States' consumption increased by 25%. Much of this global growth has been in less developed countries. (In the next two decades, estimates are that energy consumption will rise by over 100% in developing nations, an increase of over 3% per year. Most of this growth will occur in the developing nations of Asia, mainly China and India.) With this growth has been a decline in urban air quality as well as serious land and water degradation. Because fossil fuels represent almost 90% of our consumption, we continue to increase carbon dioxide emissions, which may alter the earth's climate irreversibly. The proper use of energy requires consideration of social issues as well as technological ones. Sustained economic growth in this century, together with improvements in the quality of everyone's lives, may be possible only by the well-planned and efficient use of limited energy resources and the development of new energy technologies.

B. Energy Use and the Environment

We live in an age of environmental awareness. Politicians would have a hard time getting elected if they did not at least state they had a concern for the environment. Many changes in the environment have occurred in the forty years since the first Earth Day of April 22, 1970, and some are listed in the box “Our Earth—Then and Now.”

The twenty-fifth anniversary of Earth Day in 1995 focused on the progress made to our air and water quality. In air pollution, smog has declined nationally by about a third since 1970. In 1999, Los Angeles did not record one ozone reading high enough to trigger a smog alert; twenty years earlier, there were 120 smog alerts in a year. New cars in 1995 emitted about 1% of the pollution per mile of 1970 model cars! New emission standards, plus higher fuel efficiency standards (see Chapter 8 on increased mpg), made 2010 even better for reduced emissions. Sulfur dioxide emissions, the primary cause of acid rain, have fallen by a third since 1970. In 1970, only about a quarter of our rivers met federal standards for fishing and swimming; in 1995, about 60% did. These accomplishments did not come about without great efforts. Federal and state expenditures for pollution abatement

FOCUS ON 1.1 OUR EARTH—THEN AND NOW

	1970	1990	2010
World population	3.3 billion	5.4 billion	6.8 billion
10³ Tons of lead emitted, United States	204	5	1
Tons of waste recycled	8 million	49 million	83 million
Tons of garbage generated annually in United States	121 million	160 million	250 million
Percentage of oil imported to United States	23%	51%	53%
Percentage of federal budget spent for environment	3%	1.5%	1.2%
Atmospheric CO₂ concentration (ppM)	325	350	384
World CO₂ emissions, 10⁹ tons/yr	14	21	31

Source: eia.gov and epa.gov

and control have risen sharply since 1970. However, concerns over federal spending, the national debt, and the role of the federal government continue to prompt legislative drives for drastic environmental law reforms and modifications in regulations affecting clean air and water, toxic waste, pesticides, endangered species, and so on.

The use of our energy resources is one of the major factors affecting the environment. (Our use of chemicals is another.) Increased use of fossil fuels since the beginning of the industrial age has increased the carbon dioxide concentration in the atmosphere by 35% and has also increased the earth's temperature (Fig. 1.1). Warmer global temperatures can lead to a melting of the polar ice caps and higher ocean levels, which will force a movement of population away from low-lying land near the seas. It can also mean a shift of agricultural areas as precipitation patterns move northward as well as increased disease.

Besides the use of energy resources, the gathering of those resources can impact the environment. A recent case in point is the oil well blowout in the Gulf of Mexico in April 2010. Damage to a well 1 mile below the surface of the Gulf allowed oil to flow into the Gulf for 3 months, releasing 200 million gallons of crude oil—the largest oil spill disaster in the world (see Fig. 1.2).

Disposing of our garbage is also an increasingly serious environmental problem. Americans generate almost 4.5 pounds of garbage per person per day—that's more than 3 tons per family per year and twice the rate of generation by Europeans. We're running out of acceptable places to bury our garbage. We have gone from 14,000 landfills in 1970 to less than 1600 today, for more people. Do we deal with solid waste by

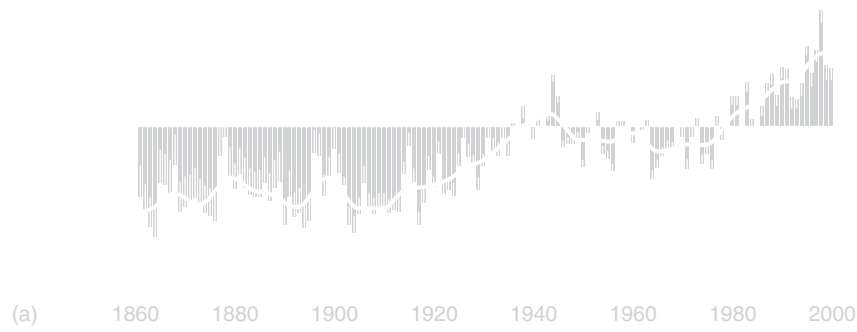


Figure 1.1 Correlation among global temperature change, atmospheric carbon dioxide, and methane concentrations displayed in order. (Intergovernmental Panel on Climatic Change—IPCC) A more convincing correlation between carbon dioxide concentrations and the earth's temperature over the past 400,000 years is shown in Figure 9.1 in Chapter 9. (Source: Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Figure 2-3, Figure 2-1. Cambridge University Press. Reproduced by permission.)

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