Energy and the Environment

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MISCELLANEOUS FACTORS

1 centimeter = 0.3937 inch; 1 inch = 2.54 cm

1 micron (μm) = 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 = 1,000 cm^3 = 0.264 gal

1 gallon = 0.1337 ft^3 = 3.885 liter

1 barrel (bbl) = 42 gal = 159.1 liter

1 kilogram = 2.2046 lb; 1 pound = 16 oz = 0.453 kg

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

1 therm = 100,000 Btu

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

1 kilowatt = 1,000 J/sec = 239 cal/sec = 3,413 Btu/hr = 1.341 hp

1 horsepower = 550 ft · lb/sec = 746 W

1 year = 3.15×10^7 sec

1 acre foot = 325,804 gallons

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

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

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

density of propane = 0.50 gm/cm^3

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

heat capacity of air = 1000 J/kg · K = 0.019 Btu/ft^3·°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	7.343×10^{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	1.19×10^{-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}

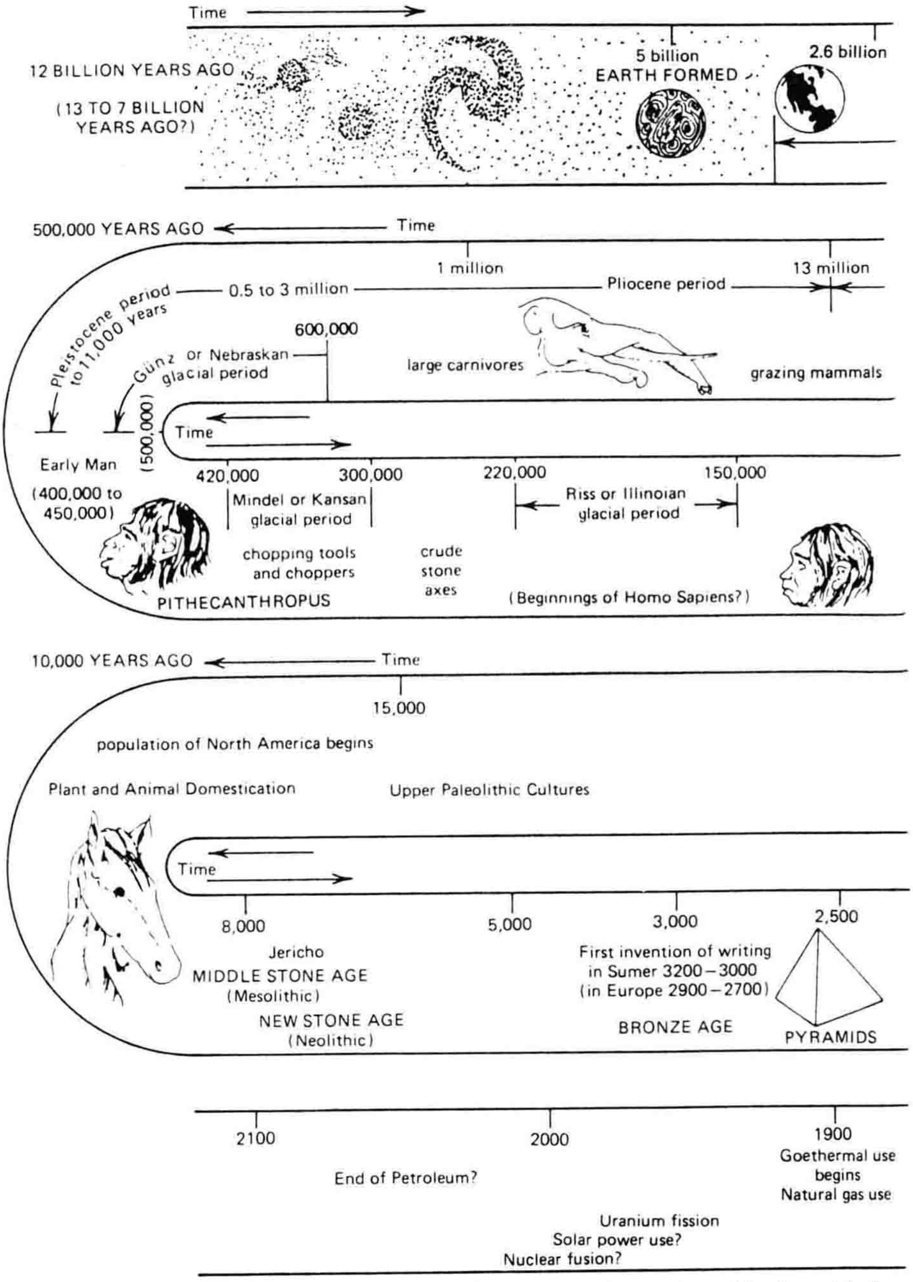
Energy Equivalents

	J	kWh	Btu
Crude petroleum (42 gallon barrel)	6.12×10^{9}	1700	5.80×10^{-4}
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}

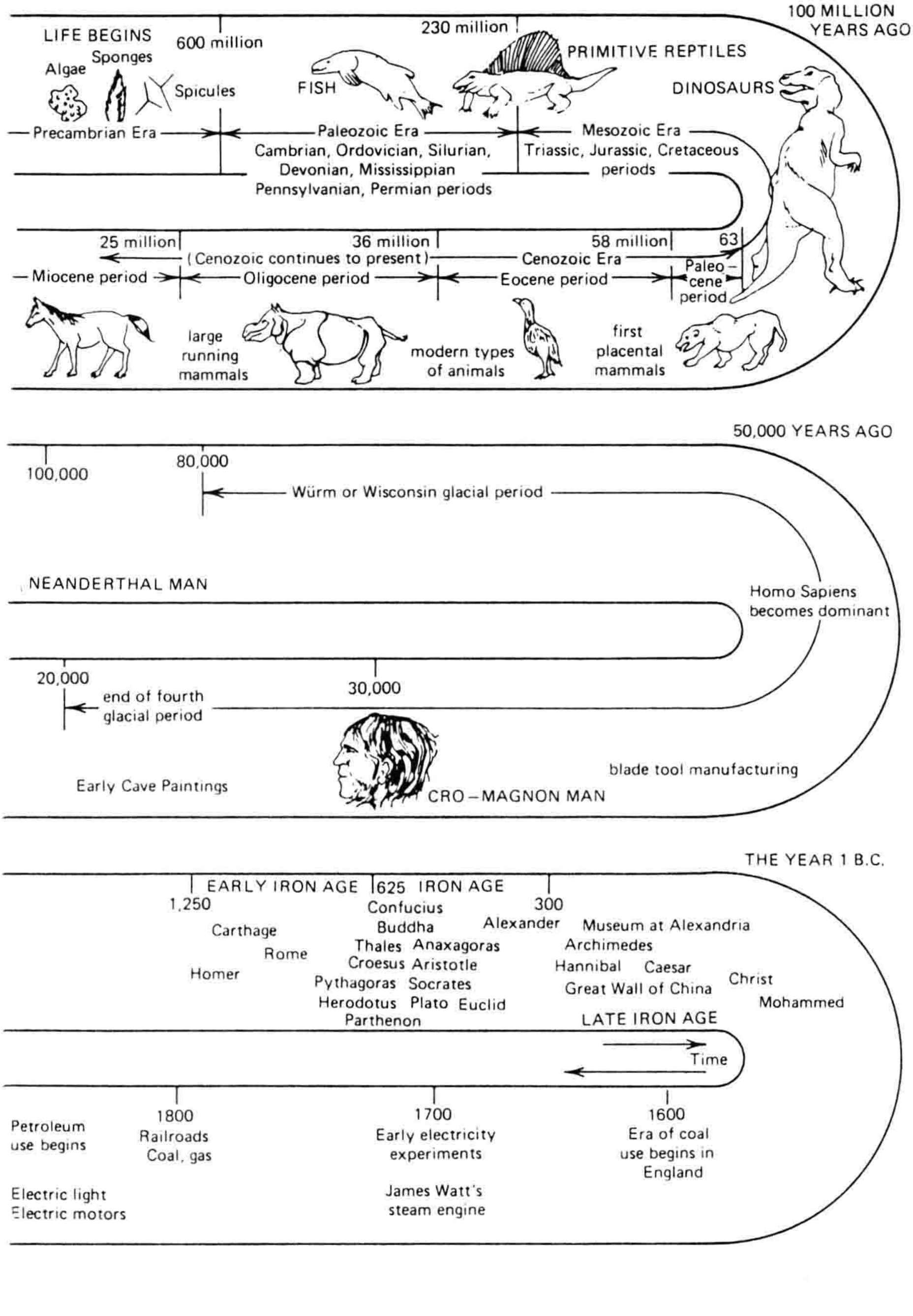
[a] 1 ton = 2000 lb = 0.907 tonne.

[b] At STP.

[c] The U.S. gallon is used in this text. The Imperial gallon used in Canada and Great Britain equals 1.200 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
Paleocene 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.
EARLY IRON AGE
1,250
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
1700
1600
Petroleum use begins
Railroads
Coal, gas
Electric light
Electric motors
Early electricity experiments
James Watt's steam engine
Era of coal use begins in England

Energy and the Environment

PREFACE

It was not until the year 1973 that 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 common for motorists to spend hours waiting in line at a filling station to obtain a tank of gasoline. At times the customer was limited to a five 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 until 1988. 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 underlying problems remain.

The problems of energy are complex and go far beyond questions of the immediate availability of motor fuel. These issues affect the United States and the world in general and there is no sign of a pending solution. Evidence is growing that many of the problems are becoming more severe with the passage of time as our fossil fuels diminish and the citizens of developing countries aspire to share more fully in the "good life." Beyond the supply side of the energy problem, we see the effects of emissions on the local and global atmosphere. We continue to experience oil spills, and we have no generally accepted solution to the problem of radioactive waste disposal.

The topics of energy and the environment are obviously crucial to all of us, and effective policies at the national level depend on the actions of an informed citizenry. To meet this need, courses dealing with energy and the environment are being taught at universities and colleges in the United States and elsewhere. *Energy and the Environment* was created from the experience the authors have had in teaching such courses for more than twenty years at The University of Colorado in Boulder. An earlier text first published fourteen years ago was intended for a two-semester course; it was distinctly quantitative and focussed on technical analysis of these issues. It has since become apparent that there is also a need for a text appropriate for a one-semester course, with a more descriptive treatment of the subject.

The present text deals with the core subjects of energy and the environment. With respect to energy, we have tried to cover 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 pollution. When the topics 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.

This text 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 slowly along with the material under discussion.

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."

Acknowledgments

Many people have been of great help to us as we have sought to obtain and organize new material for this text. In particular, we wish to thank Dr. Robert Cohen for providing helpful material on ocean energy, explicitly 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 much useful information on global warming. In addition, Stacy Davis of Oak Ridge National Laboratory was very helpful in providing definitive data on transportation energy matters. Thomas Boden of Oak Ridge National Laboratory helped us obtained up-to-date data on atmospheric carbon dioxide. We are grateful for this assistance.

Throughout our years of teaching about energy and the environment, and in the preparation of this text, our colleague, Professor A. A. Bartlett of the Department of Physics at the University of Colorado in Boulder, has been a constant source of information and perspective on this subject. We thank him for his continuing support and encouragement.

Two years ago, several reviewers evaluated the proposal for this text, along with sample material prepared by the authors. Those who helped at this early stage were: Professor Gregory Greer of Normandale Community College; Professor Jack A. Kaeck of Chicago State University; Professor John R. Kalafut of the University of Scranton; Professor V. Paul Kenney of the University of Notre Dame, and Professor Roger E. Mills of the University of Louisville. Their comments and points of view have assisted in the development of the text.

The manuscript for this text was reviewed in a late, almost final, stage of its development by Professor Philip E. Best of the University of Connecticut–Storrs, Professor Ljubisa R. Radovic of Pennsylvania State University, and Professor Don D. Reeder, of the University of Wisconsin–Madison. Their insights and suggestions for improvements have been most helpful.

The assistance provided by the staff at Wiley has been invaluable. Some of them are identified on the copyright page at the beginning of this book. In particular, our interactions with Stuart Johnson, Cynthia Rhoads, Catherine Donovan, Kim Khatchatourian, Dawn Stanley and Sandra Russell have been important in the preparation of this text. We thank them for their patience and special efforts.

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CONTENTS

CHAPTER 1

Energy Fundamentals, Energy Use in an Industrial Society

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 85% of the fuel 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 less than one percent 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 1989. The definition of QBtu will be given in Section 1.5.

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 in only a few decades. 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