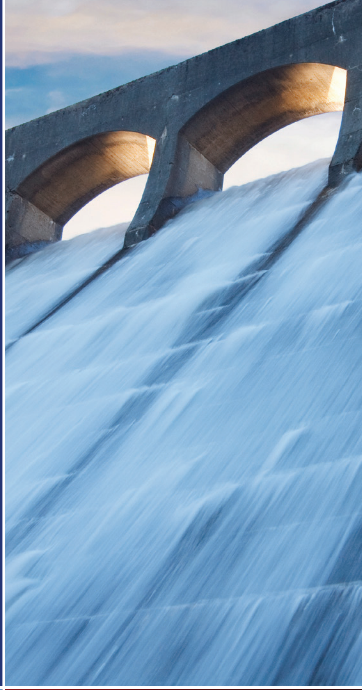
ENERGY AND THE ENVIRONMENT

Abbas Ghassemi, Series Editor

INTRODUCTION TO RENEWABLE ENERGY

SECOND EDITION



Vaughn Nelson

Kenneth Starcher

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Abbas Ghassemi
New Mexico State University

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Preface

The big question: how do we use science and technology such that spaceship Earth will be a place for all life to exist? We are citizens of Earth, and within your lifetime, there will be major decisions over the following: energy (including food), water, minerals, space, and war (which we can state will happen with 99.9% probability). These previous statements were made over 30 years ago, when Nelson first taught introductory courses on wind and solar energy. Since then, the United States has been involved in a number of armed conflicts, so my prediction on war has been fulfilled. The era of armed conflict over resources has already started—Oil War I (Gulf War) and Oil War II (Iraq War)—and a sustainable-energy future primarily fueled by renewable energy is paramount to reduce the possibility of an Oil War III between China and the United States over dwindling supplies of petroleum. This is also the opinion of one of my Chinese colleagues working in renewable energy.

We are over 7 billion and heading toward 11 billion people, and we are all participants in an uncontrolled experiment on the effect of human activities on the Earth's environment. Renewable energy is part of the solution to the problem of finite resources of fossil fuels and the environmental impact of greenhouse gases. Renewable energy is now part of national policies with significant goals for percentage increase in generation of energy within the next decades. The reason is that there are large amounts of renewable energy in all parts of the world; in contrast to fossil fuels and minerals, renewable energy is sustainable, and it reduces greenhouse gas emissions. The growth of renewable energy has been very large, at 20% per year since 2005; however, this large growth rate is attributable to the original low levels of renewable energy generation, except for hydroelectric power generation, growth for which is around 2% per year. Hydroelectric power still remains the top source of renewable-energy generation, with an installed capacity of 1,000 GW; however, at the end of 2014, the installed capacity of wind farms was 360 GW and photovoltaics was 180 GW (a significant part of new electric plant capacity from all sources). Compare these values with the numbers from the first edition of this book (2011): installed capacity energy from wind farms was 158 GW and from photovoltaics was 23 GW.

Policies for supporting renewable energy have spread from 48 countries in 2004 to over 140 countries in 2014. Renewable energy targets along with feed-in tariffs have had the biggest impact on increasing the renewable energy market. In 2004, the majority of local governments did not consider the renewables in their energy supply, and now many of them have become leaders in advancing renewable energy, some even setting targets of 100% renewables. The future for renewable energy is very bright and you can be a part of that future by working in the field or by supporting the implementation of renewable energy.

Vaughn Nelson
and
Kenneth Starcher
West Texas A&M University

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We are deeply indebted to colleagues, present and past, at the Alternative Energy Institute (AEI), West Texas A&M University (WTAMU), the Wind Energy Group at the Agricultural Research Service, and the U.S. Department of Agriculture, Bushland, Texas. The students in our classes and the students who worked at AEI provided valuable insight and feedback. We thank many others who worked with us at the AEI and the U.S. Department of Agriculture, especially the numerous international researchers and interns. We thank the Instructional Innovation and Technology Laboratory, WTAMU, for the computer drawings, and Robert Avant, Texas A&M Agri-Life Research, who reviewed Chapter 10, on bioenergy.

Vaughn: I express my gratitude to my wife, Beth, who has put up with me all these years. Dana and Vaughn Nelson (my grandchildren) assisted my efforts, especially with the PowerPoint presentations.

Ken: I credit my wife, Madeleine, with making me get up each morning and making it well worthwhile to come home each evening. I have never really had a "job," but the lifetime of involvement in renewables has been worth all the years of doing it.

Authors

Vaughn Nelson, PhD, has been involved with renewable energy, primarily wind energy, since the early 1970s. He is the author of 3 books and 4 CDs, has published over 50 articles and reports, was the principal investigator on numerous grants, and has given over 60 workshops and seminars from the local to the international level. His primary work has been on wind resource assessment, education and training, applied R&D, and rural applications of wind energy. Presently, he retired from West Texas A&M University (WTAMU). He was director of the Alternative Energy Institute (AEI) from its inception in 1977 through 2003 and then returned for another year in July 2009. He retired as the dean of the Graduate School, Research and Information Technology, WTAMU, in 2001. He served on Texas state committees, most notably the Texas Energy Coordination Council during its 11-year existence. He has received three awards from the American Wind Energy Association, one of which was the Lifetime Achievement Award in 2003; received an award as a Texas Wind Legend in 2010 from the Texas Renewable Industries Association; received an award in 2013 for Outstanding Wind Leadership in Education from Wind Powering America; and served on the board of directors for state and national renewable energy organizations. One of his projects was a renewable energy demonstration building at the AEI Wind Test Center. Dr. Nelson developed the material for a new online course in renewable energy at WTAMU in the spring of 2010, and the first edition of this book was the result. Dr. Nelson is the author of *Wind Energy* (2009, 2nd ed., 2013) and *Renewable Energy and the Environment* (2011). He received the Lifetime Achievement Award from the American Wind Energy Association in 2003.

Dr. Nelson's degrees include a PhD in physics from the University of Kansas, an EdM from Harvard University, and a BSE from Kansas State Teachers College, Emporia. He was at the Departamento de Física, Universidad de Oriente, Cumana, Venezuela, for two years and then at WTAMU from 1969 to 2003.

Kenneth Starcher began his college career and involvement with renewables in the fall of 1976. This led to a BS in physics/computer science at West Texas State University (1980). In 1980–81 he took courses in electrical engineering, electronics, and physics at Texas Tech University. He earned an MS in engineering technology at WTAMU (1995) and then took some courses in agricultural economics at WTAMU.

Starcher has been a field worker for most of the projects at the Alternative Energy Institute (AEI) since 1980. He has been the educational funnel for onsite training and public information for students and public workshops for AEI. He has served as a trainer at wind and solar training workshops locally, nationally, and internationally. He has served as a research technician, research associate, assistant director, director, and associate director (training, education, and outreach) for AEI over the past 35 years.

Starcher served as a board member of the American Wind Energy Association, is on the executive board of Class 4 Winds and Renewables, was chosen as the individual member of the year for Texas Renewable Energy Association in 2005, was chosen as the small wind educator at the Small Wind Conference in 2010, and was awarded an Outstanding Wind Leadership Education Award from Wind Powering America in 2013.

Starcher has installed and operated more than 85 different renewable energy systems, ranging in scale from 50 W to 500 kW. He has served as a consultant for wind companies in the United States and produced wind resources maps for counties, states, and Thailand and Honduras.

1 Introduction

1.1 ENERGY AND SOCIETY

Industrialized societies run on energy, a tautological statement in the sense that it is obvious. Population, gross domestic product (GDP), consumption and production of energy, and production of pollution for every country in the world are interrelated. The United States has less than 5% of the world population; however, in the world, the United States generates around 22% of the gross production and 16% of the carbon dioxide emissions and is at 18% for energy consumption (Figure 1.1). Notice that the countries listed in Figure 1.1 consume around 70% of the energy and produce around 70% of the world GDP and carbon dioxide emissions. The developed countries consume the most energy and produce the most pollution, primarily due to the increase in the amount of energy per person. On a per person basis, the United States is considered the worst for energy consumption and carbon dioxide emission.

The energy consumption in the United States increased from 34 exajoules (32 quads) in 1950 to a peak of 107 EJ (101 quads) in 2007, and because of the recession and more efficient use, consumption was 102 EJ (97 quads) in 2013. The oil crisis of 1973 showed that efficiency is a major component in gross national product and the use of energy. However, you must remember that correlation between GDP and energy consumption does not mean cause and effect.

It is enlightening to consider how the United States has changed in terms of energy use since World War II. Ask your grandparents about their lives in the 1950s and then compare the following with today:

Residential: Space heating and cooling, number of lights, and amount of space per person
Transportation: Number and types of vehicles in the family
Commercial: Space heating and cooling for buildings and lights
Industrial: Efficiency

A thought on energy and GDP: A solar clothes drying (a clothes line) does not add to the GDP, but every electric and gas dryer contributes; however, they both do the same function. We may need to think in terms of results and efficient ways to accomplish a function or process and the actual life-cycle cost. Why do we need heavy cars or sport utility vehicles with big motors that accelerate rapidly to transport people?

Now the underdeveloped part of the world, primarily the two largest countries in terms of population (China $1.3 * 10^9$ and India $1.1 * 10^9$), is beginning to emulate the developed countries in terms of consumption of energy, consumption of material resources, and greenhouse gas emissions. One dilemma in the developing world is that a large number of villages and others in rural areas do not have electricity.

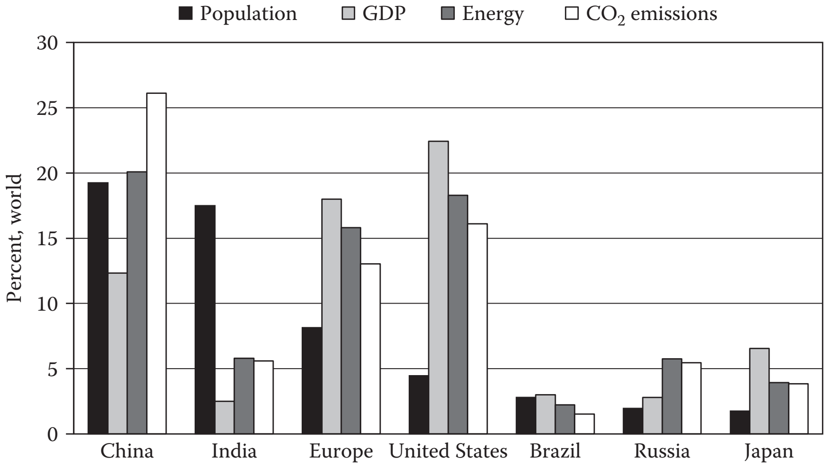

FIGURE 1.1 Comparisons, percent of world, for population (rank in world), gross domestic product, energy consumption, and carbon dioxide emission.

1.2 TYPES OF ENERGY

There are many different types of energy. *Kinetic energy* is energy available in the motion of particles, for example, wind or moving water. Potential energy is the energy available because of the position between particles, for example, water stored in a dam, the energy in a coiled spring, and energy stored in molecules (gasoline). There are many examples of energy: mechanical, electrical, thermal (heat), chemical, magnetic, nuclear, biological, tidal, geothermal, and so on.

In reality there are only four generalized interactions (forces between particles) in the universe: nuclear, electromagnetic, weak, and gravitational [1]. In other words all the different types of energy in the universe can be traced back to one of these four interactions (Table 1.1). This interaction or force is transmitted by an exchange particle. The exchange particles for electromagnetic and gravitational interactions have zero rest mass and so the transfer of energy and information is at speed of

TABLE 1.1
Information for Generalized Interactions

Interaction	Particle	Strength	Range (m)	Exchange Particle
Nuclear (strong)	Quarks	1	10^{-15}	Gluons
Electromagnetic	Charge	10^{-2}	Infinite	Photon
Weak	Leptons	10^{-6}	10^{-18}	Weakons[a]
Gravitational	Mass	10^{-39}	Infinite	Graviton

[a] My name for exchange particles (intermediate vector bosons).

light, $3 * 10^8$ m/s (186,000 miles/s). Even though the gravitational interaction is very, very, very weak, it is noticeable when there are large masses. The four interactions are a great example of how a scientific principle covers an immense amount of phenomena.

The source of solar energy is the nuclear interactions at the core of the Sun, where the energy comes from the conversion of hydrogen nuclei into helium nuclei. This energy is primarily transmitted to the Earth by electromagnetic waves, which can also be represented by particles (photons). In this course we will be dealing primarily with the electromagnetic interaction, although hydro and tides are energy due to the gravitational interaction and geothermal energy is due to gravitational and nuclear decay.

We will use exponents to indicate large and small numbers. The exponent indicates how many times the number is multiplied by itself, or how many places the decimal point needs to be moved. Powers of 10 will be very useful in order of magnitude problems, which are rough estimates.

$$10^3 = 10 * 10 * 10 = 1000$$

$$10^{-3} = \frac{1}{10^3} = 0.001$$

Note there is a discrepancy between the use of billions in the United States (10^9) and England (10^{12}). If there is a doubt, we will use exponents or the following notation for prefixes.

Factor	Name	Symbol	Factor	Name	Symbol
10^{-12}	pico	p	10^3	kilo	k
10^{-9}	nano	n	10^6	mega	M
10^{-6}	micro	μ	10^9	giga	G
10^{-3}	milli	m	10^{12}	tera	T
			10^{15}	peta	P
			10^{18}	exa	E

1 quad = 1.055 exajoules

1.3 RENEWABLE ENERGY

Solar energy is referred to as renewable and/or sustainable energy because it will be available as long as the Sun continues to shine. Estimates for the remaining life of the main stage of the Sun are another 4 to 5 billion years. The energy from the Sun, electromagnetic radiation, is referred to as *insolation or solar energy*. The other renewable energies are wind, bioenergy, geothermal, hydro, tides, and waves. *Wind energy* is derived from the uneven heating of the Earth's surface due to more heat input at the equator with the accompanying transfer of water and thermal energy by evaporation and precipitation. In this sense, rivers and dams for hydro energy are stored solar energy. The third major aspect of solar energy is the conversion of solar energy into biomass by photosynthesis. Animal products such as oil from fat and biogas from manure are derived from solar energy. *Geothermal energy* is due to heat from the Earth from decay of radioactive particles and residual heat from gravitation during formation of the Earth. Volcanoes are fiery examples of geothermal energy reaching the surface from the interior, which is hotter than the surface. *Tidal energy* is primarily due to the gravitational interaction of Earth and Moon.

Overall, 14% of the world's energy comes from *bioenergy*, primarily wood and charcoal, but also crop residue and even animal dung for cooking and some heating. This contributes to deforestation and the loss of topsoil in developing countries. Production of ethanol from biomass is now a contributor to liquid fuels for transportation, especially in Brazil and the United States.

In contrast, fossil fuels are stored solar energy from past geological ages. Even though the quantities of oil, natural gas, and coal are large, they are finite and for the long term of hundreds of years, they are not sustainable.

1.4 ADVANTAGES/DISADVANTAGES

The advantages of renewable energy are sustainable (non-depletable), ubiquitous (found everywhere across the world in contrast to fossil fuels and minerals), and essentially non-polluting. Note that wind turbines and photovoltaic panels do not need water for the generation of electricity, in contrast to steam plants fired by fossil fuels and nuclear power.

The disadvantages of renewable energy are variability and low density, which in general results in higher initial cost. For different forms of renewable energy, other disadvantages or perceived problems are visual pollution, odor from biomass, avian and bat mortality with wind turbines, and brine from geothermal. Wherever a large renewable facility is to be located, there will be perceived and real problems to the local people. For conventional power plants using fossil fuels, for nuclear energy, and even for renewable energy, there is the problem of *not in my backyard*.

1.5 ECONOMICS

Business entities always couch their concerns in terms of economics (money). We cannot have a clean environment because it is uneconomical. Renewable energy is not economical in comparison to coal, oil, and natural gas. We must be allowed to continue our operations as in the past, because if we have to install new equipment to reduce greenhouse gas emissions, we cannot compete with other energy sources, and finally, we will have to reduce employment, and jobs will go overseas.

The different types of economics to consider are pecuniary, social, and physical.

Pecuniary is what everybody thinks of as economics, *money*. On that note, we should be looking at life-cycle costs, rather than our ordinary way of doing business, low initial costs. Life-cycle costs refer to all costs over the lifetime of the system.

Social economics are those borne by everybody and many businesses want their environmental costs to be paid by the general public. A good example is the use of coal in China, as they have laws (social) for clean air, but they are not enforced. The cost will be paid in the future in terms of health problems, especially for the children today. If environmental problem(s) affect(s) someone else today or in the future, who pays? The estimates of the pollution costs for the generation of electricity by coal is $0.005 for 0.10/kWh.

Physical economics is the energy cost and the efficiency of the process. There are fundamental limitations in nature due to physical laws. Energetics, which is the energy input versus energy in the final product for any source, should be positive. For example production of ethanol from irrigated corn has close to zero energetics. So, physical economics is the final arbitrator in energy production and consumption. In the end, *Mother Nature always wins* or the corollary, pay now or probably pay more in the future.

Finally, we should look at incentives and penalties for the energy entities. What each entity wants are subsidies for themselves and penalties for their competitors. Penalties come in the form of taxes, environmental, and other regulations, while incentives come in the form of subsidies, break on taxes, do not have to pay social costs on the product, and the government pays for research and development. How much should we subsidize businesses for exporting overseas? It is estimated that we use energy sources in direct proportion to the incentives that source has received in the past. There are many examples of incentives and penalties for all types of energy production and use.

1.6 CLIMATE CHANGE

Climate change, which previously was referred to as *global warming*, is a good example that physical phenomena do not react to political or economic statements. Global warming is primarily due to human activity. "Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.... The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture" [2]. Concentrations of carbon dioxide in the atmosphere (Figure 1.2) are projected to double with future energy use based on today's trend [3,4].

The Kyoto Protocol of 1996 to reduce greenhouse gas emissions became effective in 2005 as Russia became the 55th country to ratify the agreement. The goal was for the participants collectively to reduce emissions of greenhouse gases by 5.2% below the emission levels of 1990 by 2012. While the 5.2% figure was a collective one, individual countries were assigned higher or lower targets and some countries were permitted increases. For example, the United States was expected to reduce emissions by 7%. However, this did not happen, as the United States did not ratify the treaty because the perceived economic costs would be too large and there were not enough provisions for developing countries, especially China, to reduce future emissions. Note that for the past few years, U.S. emission of carbon dioxide has decreased due to increased use of natural gas and increase in wind and solar power for the production of electricity, and because of less economic activity due to recession of 2008.

If participant countries continue with emissions above the targets, then they are required to engage in emissions trading. Notably, participating countries in Europe are

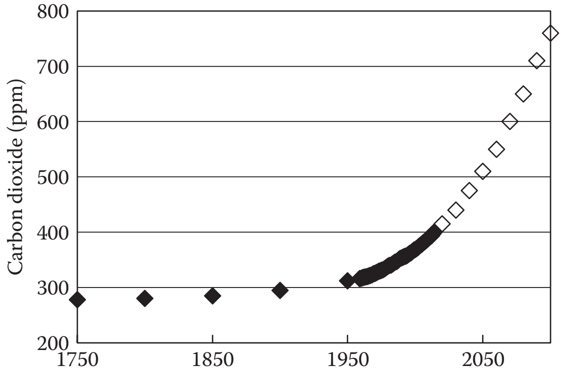

FIGURE 1.2 Carbon dioxide in the atmosphere and projected growth with no emission reductions.

using different methods for carbon dioxide trading, including wind farms and planting forests in other countries. Carbon dioxide emissions will still increase, even if nations reduce their emissions to 1990 levels, because of population growth and increase in energy use in the underdeveloped world. As the Arctic thaws, then methane, a more potent greenhouse gas than CO_2, would further increase global warming [5].

Increased temperatures and the effect on weather and sea level rise are the major consequences. Overall, the increased temperature will have negative effects compared to the climate of 1900–2000. By 2100, sea levels are projected to increase by 0.2 to 1 m, with an increase of 2 m unlikely, but physically possible. With positive feedback due to less sea ice and continued increase in carbon dioxide emissions, the melting of the Greenland ice sheets would increase the sea level by over 7 m and the West Antarctic Ice Sheet would add another 5 m. The large cities near the oceans will have to be relocated or build massive infrastructures to keep out the ocean. Who will pay for this, national or local governments?

1.7 ORDER OF MAGNITUDE ESTIMATES

In terms of energy consumption, production, supply and demand, and design for heating and cooling, estimates are needed and an order of magnitude estimate will suffice. By order of magnitude, we mean an answer to within a power of 10.

Example

How many seconds in a year. With a calculator, it is easy to determine

$$365 \text{ days} * 24 \text{ h/day} * 60 \text{ min/h} * 60 \text{ s/h} = 31{,}536{,}000$$

When you round to one significant digit, this becomes $3 * 10^7$ s.

For an order of magnitude estimate for the above multiplication, round each number with a power of 10, then multiply numbers and add the powers of 10

$$4 * 10^2 * 2 * 10^1 * 6 * 10^1 * 6 * 10^1 = 4*2*6*6*10^5$$
$$= 288*10^5 = 3*10^2*10^5 = 3*10^7 \text{ s}$$

1.8 GROWTH (EXPONENTIAL)

Our energy dilemma can be analyzed in terms of fundamental principles. It is a physical impossibility to have exponential growth of any product or exponential consumption of any physical resource in a finite system. As an example, suppose Mary started employment with $1/year; however, her salary is doubled every year, a 100% increase (Table 1.2, Figure 1.3). Notice that after 30 years, her salary is one billion dollars. Also notice that for any year, the amount needed for the next period is equal to the total sum for all the previous periods plus one. The mathematics of exponential growth is given in Appendix I.

TABLE 1.2
Exponential Growth with a Doubling Time of 1 Year

Year	Salary ($)	Amount = 2^t	Cumulative ($)
0	1	2^0	1
1	2	2^1	3
2	4	2^2	7
3	8	2^3	15
4	16	2^4	31
5	32	2^5	63
t		2^t	$2^{t+1} - 1$
30	$1 * 10^9$	2^{30}	$2^{31} - 1$

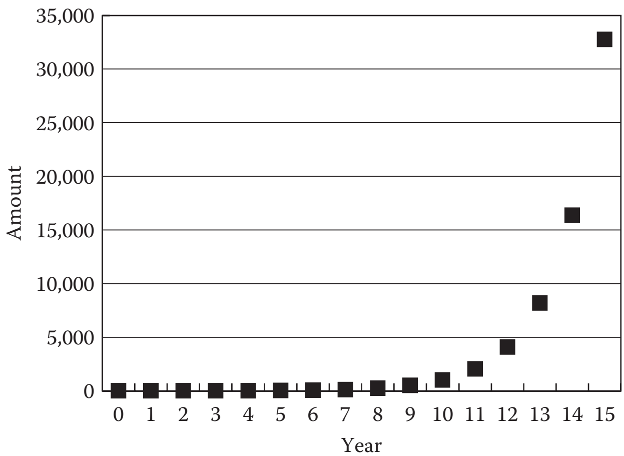

FIGURE 1.3 Salary with a doubling time of 1 year to show exponential growth.

Another useful idea is doubling time, $T2$, for exponential growth, which can be calculated by

$$T2 = \frac{69}{R} \tag{1.1}$$

where:

R is the % growth per unit time

Doubling times for some different year rates are given in Table 1.3.

There are numerous historical examples of growth: population, 2%–3%/year; gasoline consumption, 3%/year; world production of oil, 5%–7%/year; and electrical consumption, 7%/year. If we plot the value per year for smaller rates of growth (Figure 1.4), the curve would be the same as Figure 1.3, only the timescale along

TABLE 1.3
Doubling Times for Different Rates of Growth

Growth (%/year)	Doubling Time Years
1	69
2	35
3	23
4	18
5	14
6	12
7	10
8	8
9	8
10	7
15	5

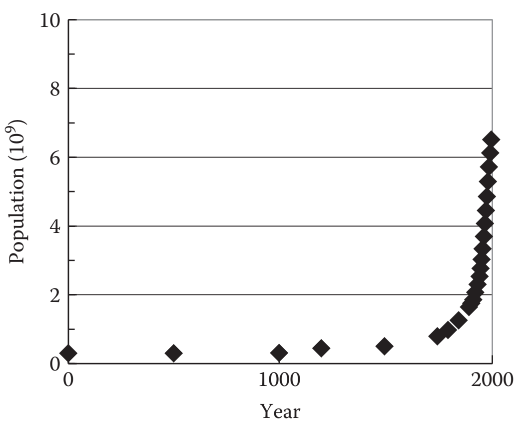

FIGURE 1.4 World population showing exponential growth.