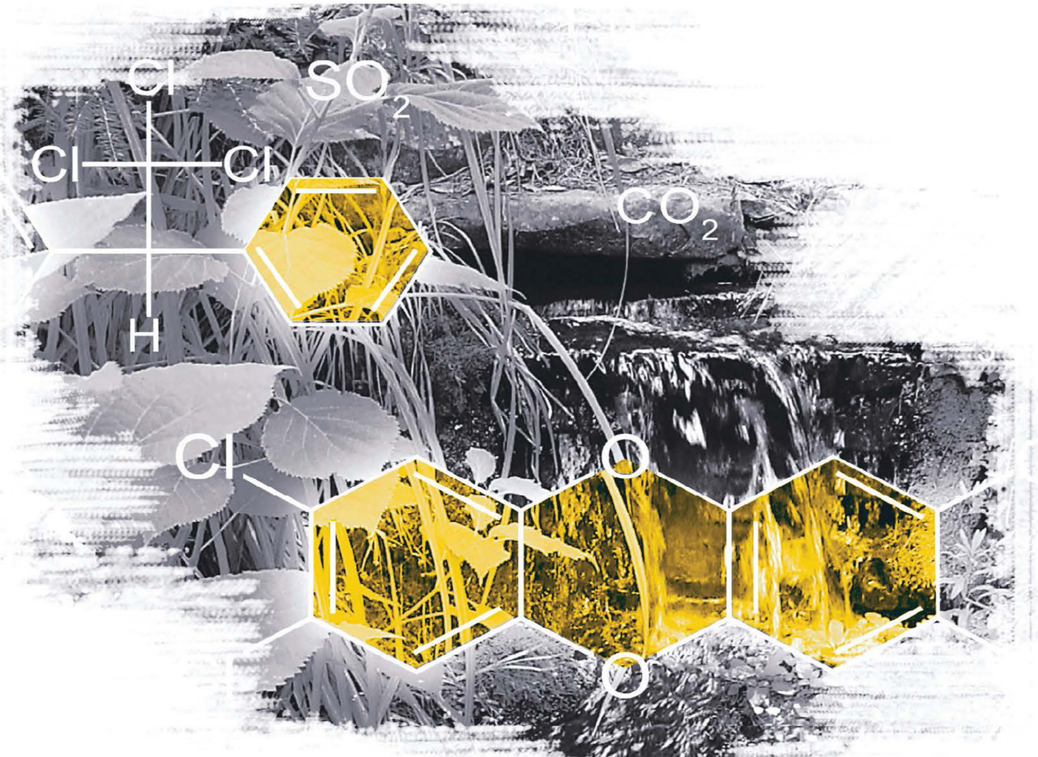
Third Edition

Environmental Chemistry in Society



James M. Beard
Ruth Ann Murphy

CRC Press
Taylor & Francis Group

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Periodic Table of the Elements

Atomic Number → 1 **H** ← Symbol
Name → Hydrogen 1.008 ← Atomic Weight

State of matter (color of name)
GAS LIQUID SOLID UNKNOWN

Subcategory in the metal–metalloid–nonmetal trend (color of background)
- Alkaline metal
- Lanthanide
- Transition metal
- Alkaline earth metal
- Actinide
- Post-transition metal
- Metalloid
- Polyatomic nonmetal
- Diatomic nonmetal
- Noble gas
- Unknown chemical properties

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 **H** Hydrogen 1.008																	2 **He** Helium 4.002602
3 **Li** Lithium 6.94	4 **Be** Beryllium 9.0121831											5 **B** Boron 10.81	6 **C** Carbon 12.011	7 **N** Nitrogen 14.007	8 **O** Oxygen 15.999	9 **F** Fluorine 18.998403163	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.98976928	12 **Mg** Magnesium 24.305											13 **Al** Aluminium 26.9815385	14 **Si** Silicon 28.085	15 **P** Phosphorus 30.973761998	16 **S** Sulfur 32.06	17 **Cl** Chlorine 35.45	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955908	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938044	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933194	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.630	33 **As** Arsenic 74.921595	34 **Se** Selenium 78.971	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.798
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90584	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90637	42 **Mo** Molybdenum 95.95	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.414	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.293
55 **Cs** Caesium 132.90545196	56 **Ba** Barium 137.327	57 - 71 Lanthanoids	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.94788	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.084	79 **Au** Gold 196.966569	80 **Hg** Mercury 200.592	81 **Tl** Thallium 204.38	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98040	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 - 103 Actinoids	104 **Rf** Rutherfordium (267)	105 **Db** Dubnium (268)	106 **Sg** Seaborgium (269)	107 **Bh** Bohrium (270)	108 **Hs** Hassium (269)	109 **Mt** Meitnerium (278)	110 **Ds** Darmstadtium (281)	111 **Rg** Roentgenium (282)	112 **Cn** Copernicium (285)	113 **Nh** Nihonium (286)	114 **Fl** Flerovium (289)	115 **Mc** Moscovium (289)	116 **Lv** Livermorium (293)	117 **Ts** Tennessine (294)	118 **Og** Oganesson (294)

57 **La** Lanthanum 138.90547	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90766	60 **Nd** Neodymium 144.242	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92535	66 **Dy** Dysprosium 162.500	67 **Ho** Holmium 164.93033	68 **Er** Erbium 167.259	69 **Tm** Thulium 168.93422	70 **Yb** Ytterbium 173.045	71 **Lu** Lutetium 174.9668
89 **Ac** Actinium (227)	90 **Th** Thorium 232.0377	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.02891	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (266)

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Third edition published 2022
by CRC Press
6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742

and by CRC Press
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Library of Congress Cataloging-in-Publication Data
Names: Beard, James M., author. | Murphy, Ruth Ann, author.
Title: Environmental chemistry in society / James M. Beard, Ruth Ann Murphy.
Description: Third edition. | Boca Raton : CRC Press, 2021. |
Includes bibliographical references and index.
Identifiers: LCCN 2021006705 (print) | LCCN 2021006706 (ebook) |
ISBN 9780367313586 (hardback) | ISBN 9780367313241 (paperback) |
ISBN 9780429316548 (ebook)
Subjects: LCSH: Environmental chemistry. | Pollutants. |
Environmental management.
Classification: LCC TD193 .B43 2021 (print) | LCC TD193 (ebook) |
DDC 628—dc23
LC record available at https://lccn.loc.gov/2021006705
LC ebook record available at https://lccn.loc.gov/2021006706

ISBN: 978-0-367-31358-6 (hbk)
ISBN: 978-0-367-31324-1 (pbk)
ISBN: 978-0-429-31654-8 (ebk)

Typeset in Times
by codeMantra

Access the Support Materials: https://www.routledge.com/9780367313586.

In Memory of Susan Wright Beard

Contents

Preface to the Third Edition

TO THE STUDENT

This book is designed for you, the student! Use it well – we are all in this together!

TO THE INSTRUCTOR

While preserving the inimitable conversational and clear tone of Dr. Beard's earlier editions, this third edition includes, in addition to data updates, impacts of the COVID-19 pandemic and helpful features such as group work activities and a test bank (available to instructors on request). The invaluable chemical background so integral to environmental matters is retained. The energy chapter is now divided into two chapters to help students process the material.

The group work activities could be used in various ways – as homework or in-class assignments, for remote learning, and as replacements for some hands-on labs.

The basic structure is given below:

Introduction	Chapter 1
Foundational material	Chapters 2,3,4,5,6,7,8
Specific background material	Chapters 9 and 13
Environmental content chapters	Chapters 7,8,10,11,12,14,15,16
Closing thoughts	Chapter 17

The intention is that all students cover Chapters 1–6, with Chapters 7 and 8 strongly encouraged but not essential. Chapters 9–16 could be covered in any order, provided Chapter 9 precedes Chapters 10 and 12, and Chapter 13 precedes Chapter 14. This arrangement of material allows instructors the freedom to cover the material in a manner that can be customized to the needs of their courses.

TO EVERYONE

While this textbook is based on an "old Earth," it is done so with the utmost respect for those who view the planet as much younger. The topics contained herein are presented in a way to be useful to all who deem stewardship of our planet to be a priority.

As Dr. Beard wrote in the second edition, "Any text, of course, can be made better." Any suggestions or corrections would be most welcome and could be sent to rmurphy@umhb.edu.

James M. Beard Ruth Ann Murphy

Preface to the Second Edition

I wrote this book because of my belief that it is important for non-science-oriented students to understand the environment. It is, after all, these very individuals who will influence the course of public policy on the environment in any democracy. Many books present environmental science to the non-science student, but few look specifically into environmental chemistry. Among the numerous chemical issues that are important to any understanding of the environment around us, all of us need to have some understanding of global warming, ozone depletion, energy sources, air pollution, acid rain, water pollution, waste disposal, and hazardous waste.

To the students who will read this book, I would point out that, although this is a college text, there is no assumption of any background in chemistry. Within the text, you will find all of the background information necessary to understand it. To the faculty who will use this book, I would like to note that this is a self-contained environmental chemistry text, in which students can find all of the background they need. The book is structured in such a way as to give students a background in science, chemistry, and toxicology before delving into such areas as energy in society, air quality, global atmospheric concerns, water quality, and solid waste management. The basic structure is given as follows:

Introduction	Chapter 1
Foundational material	Chapters 2,3,4,5,6,7
Specific background material	Chapters 8 and 12
Environmental content chapters	Chapters 7, 9, 10, 11, 13, 14, 15

The intention is that all students cover Chapters 1 to 6, with Chapter 7 strongly encouraged but not essential. All other chapters could be covered in any order, provided Chapter 8 precedes Chapters 9 and 11, and Chapter 12 precedes Chapter 13. This arrangement of material allows instructors the freedom to cover the material in a manner that can be customized to the needs of their courses.

In the second edition, the environmental data have been updated and material has been added concerning fracking, the Fukushima Daiichi power plant disaster, and the Deepwater Horizon oil rig blowout. Most of the homework questions have been rewritten to provide questions that require more critical thinking skills.

I have enjoyed writing this book and have tried to make it very readable for any college student. Any text, of course, can be made better. I would welcome any suggestions for improvement in or corrections to the text. I can be reached by email at jbeard@catawba.edu.

Acknowledgments

Many thanks to Dr. Beard for "paving the way" with his earlier editions of this text and for so graciously inviting me to join in the venture. I appreciate my granddaughter Gabrielle Murphy Goldstein, who so ably assisted with some of the artwork. Kudos to Hilary Lafoe, Jessica Poile, and all the fine folks at Taylor & Francis, for providing patient assistance and showing me that publishing is fun!

Ruth Ann Murphy

Authors

James M. Beard, PhD, earned a BA in chemistry at Manchester College (now Manchester University), Manchester, IN, 1965 and a PhD in organic chemistry at Stanford University, Stanford, CA, in 1969. After two years of teaching chemistry at Manchester College, he pursued a career as a clinical chemist. During the next 12 years, Dr. Beard worked as a product developer, quality control consultant, and administrator in both hospital and industry settings. From 1988 to 2013, Dr. Beard was a member of the faculty at Catawba College in Salisbury, NC, where he was a professor of chemistry and where he is now Professor Emeritus of Chemistry. Dr. Beard's major interest is environmental chemical education.

Ruth Ann Murphy, PhD, earned a BS in chemistry and a PhD in physical chemistry from the University of Texas at Austin, with additional graduate studies at the University of Wisconsin-Madison. After teaching appointments in chemistry at Southwestern University, Georgetown, TX, and the University of New Mexico, Albuquerque, she served as an assistant professor of chemistry and chemistry coordinator at the University of Albuquerque. As a professor of chemistry, she then chaired the division of science and math at Howard Payne University, Brownwood, TX. Since 1995, Dr. Murphy has taught at the University of Mary Hardin-Baylor, Belton, TX, where she chairs the Department of Chemistry, Environmental Science and Geology, holds the Amy LeVesconte Professorship of Chemistry, directs the Recycling Program, co-chairs the Health Professions Advisory Committee, and is Principal Investigator for the Robert A. Welch Foundation research grant. Dr. Murphy enjoys making chemistry relevant to her students by infusing environmental and other examples from daily life into her courses.

CHAPTER 1

Background to the Environmental Problem

The environment, broadly, can be construed to include nearly everything on the Earth, both living and nonliving.

As citizens of the 21st century, we humans are trying to come to terms with what we can and cannot do regarding the world around us – our environment. In the middle of the past century, there was a widespread feeling that the world was our apple. We could do with it as we pleased, and the Earth would continue to sustain us as it always has. We felt that resources were limitless and that pollution, although disagreeable, would be diluted somehow. Gradually, the world around us began to send messages that all was not well. Nature was trying to indicate that there were limits, and if we ignored them, there would be consequences. The purpose of this book is to explore some of these limits and consequences, and possibly motivate some corrective action.

1.1 INTRODUCTION

We look at our environment from the point of view of the chemistry that takes place in it. In environmental studies, it is almost impossible to separate the biological issues from the chemical ones; therefore, our chemistry emphasis will be a matter of focus. This book focuses on environmental issues that are more chemical in nature but inevitably covers some aspects of biology also.

Discussions on the environment tend to be very "human-centered." The environment includes our total surroundings. As this is a science text, the emphasis is on the physical surroundings. The environment and the laws and principles that regulate the function of the environment are discussed. From environmental discussions, it is often easy to get the impression that there is a great natural world around us from which we are separate; yet this was not always the case. Let us explore how we came to consider ourselves as separate from the natural world around us.

1.2 PREAGRICULTURAL DEVELOPMENT

Humans began to emerge as a species about 1.7–2 million years ago. The species that evolved first was not the same as humans today, but was our early ancestor. The species was known as *Homo habilis* and probably emerged in southern Africa. It is believed that these early relatives of ours were scavengers who survived by eating wild plants and the meat of dead animals. This very early human species was close to nature and survived the same way as other animal species. The only thing that may have separated this very early human species from the other animals of the time was the humans' ability to make and use simple tools. This activity was something our ancestors shared with only a few other species, in which this activity remained fairly rudimentary. Tools set humans ever so slightly off from the nature around them. In other ways, these very early humans blended with nature. They took what they required directly from the natural world around them and returned their biological wastes directly to it.

The next human species was *Homo erectus*, which evolved about 1.5 million years ago. These early humans engaged in a new activity – hunting. Hunting became a method of survival that humans used up to about 10,000 years ago. *H. erectus* was a species of **hunter–gatherers**, as was the next species, *Homo sapiens*, which emerged about 100,000–300,000 years ago and was followed by human beings as we know them, *H. sapiens sapiens*. For most of our time on Earth, *H. sapiens sapiens* have been hunter–gatherers. We appeared on the planet about 40,000 years ago and were hunter–gatherers for about 30,000 years. In this early period, humans became more and more sophisticated in their methods. As time passed, the tools used for hunting got better. Our ancestors learned to hunt in groups and to use fire to drive away wild animals from the forest. Over this period of time, the impact of humans on the environment increased dramatically. Humans could kill large numbers of animals and may have contributed to the extinction of some. The use of fire allowed these early ancestors to convert forests into grasslands. Despite all of these changes, the impact of early humans was minor when compared to today's standards. There were only a few of them, they were nomadic, and they had only their own muscle power to use. The environmental impact of these early humans was local and transient.

1.3 HORTICULTURE AND AGRICULTURE

About 10,000 years ago (8000 BCE), humankind began to take more direct control over the environment. Humans began to domesticate animals such as cattle and pigs, and cultivate specific plants that were useful for food or other purposes. This early system of production of food and useful materials was known as **horticulture**. Horticulture had certain hallmarks that distinguished it from agriculture. A modern analogy to many of the elements of horticulture would be the family garden. The plots were small and contained a large variety of plants. In growing these plants, depletion of the soil was rarely a problem because most of the people were still semi-nomadic. After 2–5 years, they would simply move on and find a new plot of ground. Such a system could go on indefinitely.

The fact that the cultivated plots were small was probably more a matter of necessity than of choice. Early humans had very limited means of breaking up the soil and had great difficulty if the ground was too hard. In very early times, cultivation was done with little more than a pointed stick. (Over a long period of time, the stick evolved into the hoe.)

In about 5000 BCE, the plow was invented. The plow changed things radically. By using domesticated animals to pull the plow, much larger fields could be cultivated. **Agriculture** developed when people figured out how to grow crops and raise livestock on what was for them a relatively large scale. When cultivation was done on a large scale, it was more logical to specialize and grow larger plots (fields) of only one crop. Because the farmer would grow more of the one crop than he needed, he could trade the excess to get other things of value. These exchanges of crops and other needed items became the basis of early trade and commerce.

Crops and livestock became the earliest forms of wealth, and land was needed to produce both. Farmers needed to acquire land, settle on it, and protect it. Farming led to the end of the nomadic lifestyle as the principal way of life. Nomadic hunter–gatherers gradually became sedentary farmers. The increased food supply and the sedentary nature of farm life led to an increase in population, as more children could be supported and the children could work on the land. Nomadic families tended to be smaller because food was less plentiful, and moving children from one place to another was difficult. Agriculture also brought with it the first indications of environmental problems. Some fields, after they were used continuously over a period of time, produced less and less as the nutrients in the soil were used up. In some cases, farmers had to pull up stakes and move on.

As farming spread to arid areas, water became just as important as land. Fairly early on in the development of agriculture, water was diverted from rivers by means of canals or ditches for the purpose of **irrigation**. Early agriculture in the Nile valley depended on water from the Nile River as it does even today.

1.4 DEVELOPMENT OF TOWNS AND CITIES

The success of agriculture in producing more food than that required by a family allowed some people to leave food production altogether. By making other products or providing services that the farmer needed, these craftsmen could trade these goods and services for food. Such individuals began to form small groupings called villages or towns. As agriculture improved and people became more sophisticated, some of the towns grew larger. Eventually, these towns became **cities**.

Cities are not merely large towns. Towns and cities differ in that cities have some type of administrative structure and organization. Often, the very early cities were organized around a central temple, and the temple servants often became the city administrators. It was not uncommon for the city government to be headed by a priest king or in some cases a god king.

Human history is very much entwined with the history of cities. In fact, the words "city" and "civilization" are both derived from the same Latin root, *civitas*. Based on the best archaeological data (Macionis and Parrillo, 2007), the oldest city in the world is Jericho, which was founded sometime between 8000 and 7000 BCE; however, large areas with related cities began to appear about 4000 BCE in Mesopotamia and Egypt.

Early cities were generally built on the banks of rivers or by the sea. The rivers were a source of water and a means of removing waste. The rivers and seas also served as routes for trade and commerce. Early cities had many restrictions. The cities were limited by the primitive transportation available for bringing food into the city. Cities also had to be small in area, as the citizens traveled on foot wherever they went. Shops, markets, jobs, and dwellings had to be close to one another. Even the increased use of horses and wagons did not change this dynamic very much. Some large cities such as Rome and Constantinople did develop, but they were exceptions rather than the rule. With the advent of the Renaissance, cities began to grow and prosper. Technological innovations improved life in the cities, which allowed them to attract more and more people. Finally, all of these innovations came together into what came to be known as the **Industrial Revolution**

1.5 INDUSTRIAL REVOLUTION, PHASE I (APPROXIMATELY 1760–1860)

Despite tremendous changes in the cultural, political, and religious nature of the world since ancient times, other elements of life were still relatively the same until 1760. Cities, although very important, were small compared to today's standard because they required a fairly large agricultural base to support them. In the previous 50 years, there had been some innovations in the field of agriculture, but most of the world's agriculture was being carried out as it had long been, with most of the energy provided by domesticated animals.

In many areas of life, things remained unchanged as well. The forms of energy used, for example, were those that had been known since antiquity. These energy sources were animal power, wood burning, water power, and wind power. There were some occasional local exceptions to these traditional power sources, such as the early and extensive use of coal as a fuel in England, as mentioned in Chapters 7 and 10, but generally, the sources of energy remained unchanged. Of the 17 chemical elements known in 1760, 9 had been known since antiquity. Everyday life changed very slowly, if at all.

The Industrial Revolution changed nearly everything about everyday life. Things such as hourly wages, standard workweeks, vacations, and many other related concepts did not exist before the Industrial Revolution. So much of how we organize our lives both individually and corporately is directly a result of the Industrial Revolution. It is impossible to present a complete account of the historical and cultural ramifications of the Industrial Revolution in a few pages; however, an attempt has been made to convey some of the significance of these revolutionary changes. One of the problems in discussing the Industrial Revolution is that it is difficult to trace the origins of the revolution to a single primary event from which everything else occurred; rather, the revolution was the result of many interconnected events occurring over a period of several decades or more.

The early Industrial Revolution occurred for the most part in England. The most obvious changes occurred in the textile, coal, and iron industries. The textile industry had been slowly mechanizing for at least 200 years before 1760. By the middle of the 18th century, factories were needed to house the large amount of machinery necessary to produce cloth. One of the essential elements needed to operate machinery was energy, and in 1750, the best source of energy was water power. To get easy access to water power, most textile factories were located in the hills of the English countryside where there were streams. Because there were fewer inhabitants in the hills, it was necessary to import labor from the cities.

With the invention of an efficient **steam engine** by **James Watt** in 1769, the location of textile factories suddenly became independent of water power. Textile factories could be located in large cities where the workforce resided, as steam could be used as the power source. These changes led to rapid development of the modern city, where large numbers of people were involved principally in factory work. In addition to steam power, which brought the jobs to the city, advances in agriculture and transportation also increased the amount of food available in the city.

The invention of James Watt's steam engine in turn depended on advances in the iron industry. One of the early giants of the iron industry was **John Wilkinson**, who had been involved with the British Navy in the production of cannons. To get the maximum power from a cannon, a precise bore of the barrel was necessary, and Wilkinson had learned how to produce such a precise bore. When Watt and his partner, Matthew Boulton, needed precisely manufactured steam cylinders and pistons, they turned to Wilkinson.

It was Wilkinson who had pushed the iron industry harder and further than anyone else. He realized that when more things were made of iron, more iron would be needed, and it would become less expensive to produce each ton of iron. Wilkinson was one of the first to understand the economy of scale. With plentiful supplies of cheap iron, factories became easier to outfit because the machines in them were made out of iron. As more factories developed, one thing all of them needed was power.

Once the steam engine was widely established, coal became the principal energy source. Coal was needed not only to power the steam engines but also to provide the heat needed to extract iron from its ore, to soften the metal in order to remove impurities, and to melt the metal to cast it into shapes. The steam engine also made coal mining more efficient. Underground coal mines had a tendency to fill up with water from seepage, and a method was needed to remove the water. Once the steam engine was perfected, water was removed from coal mines by steam power rather than by people, horses, or water power. The steam engine made the coal industry more efficient, which in turn made the coal industry better able to supply coal to produce iron and to operate the steam engines of the factories in England.

1.6 INDUSTRIAL REVOLUTION, PHASE II (APPROXIMATELY 1860–1950)

Some profound changes were seen between 1830 and 1860. Gradually, inventors depended on scientific information to chart their course in the development of new ideas. This change is evident in the evolution of the electric industry. Until the beginning of the 19th century, electricity was an interesting novelty but not of any practical value; however, many scientists carefully studied electrical phenomena. The well-known experiment carried out by **Benjamin Franklin** using a kite in a thunderstorm is one example out of many. Yet, electricity continued to be impractical as long as there was no means of producing a continuous electric current.

In 1800, **Alessandro Volta** invented the forerunner to what is known as the battery today. Despite their limited electricity-producing capacity, these batteries allowed people to use an electric current. Once electricity was available, exploration of its use began to move ahead rapidly. The idea of the mass use of electricity for lighting emerged in the last half of the 19th century. It was clear, however, that batteries could not generate the amount of electricity that was necessary. During this period, the first electric **generators** were invented. Generators could convert mechanical action into electricity. Mechanical energy could be provided by devices such as a waterwheel or a steam engine. Hence, coal, by fueling a steam engine, could provide the energy to produce electricity. Electricity began to spread to all areas of the industrial society. By the end of the 19th century, there were electric streetlights and electric streetcars in many cities, electric lights in many homes, and electric motors in many factories.

None of this would have been possible were it not for the steel industry. **Steel** is harder and stronger than most of the iron available for use. For many applications, including large electric generators, iron is either too soft or too brittle. The properties of the iron depend on the carbon content of the metal. Iron is extracted from its ore and processed using charcoal or **coke** (relatively pure carbon produced from coal). The iron picks up some of the carbon. Most iron as it is initially produced after being extracted from its ore is 2%–4% carbon and contains many impurities. This type of iron is known as **cast iron** and is extremely brittle. The iron can be worked to remove nearly all of the carbon and some of the impurities to produce **wrought iron**. Wrought iron is not brittle but is relatively soft and as a result does not hold an edge well. With the proper percentage of carbon, one can get a product with just the right combination of strength and hardness. Such a product is steel, which is an **alloy** made up of iron and 0.5%–1.5% carbon. An alloy is a metal containing more than one element; in the case of steel, those elements are iron and carbon. Steel must also have most of the impurities removed, as such materials will degrade the quality of the product.

Steel (as distinct from iron) has been known since the 12th century BCE. Steel has been in use in various cultures. The quality and carbon content of the steel vary from situation to situation. The Japanese Samurai sword has been made from steel of very exacting quality for centuries. The properties of steel for various applications are different because of the variability in carbon content. Before the middle of the

19th century, steel could be made only in small quantities because it could only be made from fairly pure batches of wrought iron. This purified iron was difficult to obtain and had to be heated with charcoal or coke for several days to produce the steel.

To produce steel on a larger scale, it was necessary to make it from cast iron, which is available in large quantities. Any process had to remove nearly all of the impurities and adjust the final carbon percentage to that desired in the final product. About 1847, William Kelly, a businessman in the United States, started work on a device that would make steel from cast iron; however, because of financial problems, he was not able to complete his project. A similar device was patented in 1856 by **Henry Bessemer**, who was working independently in England. The **Bessemer process** revolutionized steel making, but ran into competition from another process rather quickly. A German named **William Siemens**, who was living in England, developed the **open-hearth process**, and steel was being produced in France by 1864. The Bessemer process was an important development, as it opened the way to the advent of the age of steel, but it was gradually replaced by the open-hearth process, which was the major steel production method until the middle of the 20th century.

With the practical problems of steel production solved, the output of the steel industry soared. England produced 60,000 tons of steel in 1850, before the Bessemer converter was invented. By 1898, the annual English steel output was 5,000,000 tons. Worldwide production of steel went up from 560,000 tons annually in 1870 to 12,000,000 tons in 1890. The United States alone produced 10,000,000 tons in 1901.

An industry that was intertwined in many ways with the steel industry and the electric industry was the chemical industry. More than any other industry, the chemical industry typified how the second phase of the Industrial Revolution operated. In 1856, a young student from the Royal College of Chemistry in London acted on the advice of his professor and attempted the synthesis of quinine. Quinine was used to combat the effects of malaria, and the British had an empire scattered all over the world, including the tropics. To attempt this synthesis, the student, **William Henry Perkin**, worked with compounds from coal tar. Coal tar is a byproduct of the steel industry produced when coal is converted to coke. The synthesis did not work, but Perkin produced a good yield of a purple dye. Perkin immediately realized that he had a great opportunity because at that time, purple dye was very expensive. Purple was the color of royalty because its only source was a Mediterranean mollusk, and producing the dye took a very large number of mollusks. Perkin left school and, with the support of his father, went into business for himself. Thus, the chemical dye industry was born. In the dye industry, science was used to systematically search for more and more dyes. The more dyes available, the greater the profits; therefore, chemical science and the chemical industry became linked forever. This partnership spilled over into fertilizers, explosives, drugs, and plastics, to name a few areas.

The influence of the steel industry on the chemical industry can be illustrated by some events around the beginning of the 20th century. In 1898, William Crookes observed that the vast deposit of nitrates in Chile was being rapidly depleted. Nitrates

Figure 1.1 Fritz Haber.

were one of the important components of fertilizer, and many of the advances in agriculture depended on it. In 1904, a German chemist named **Fritz Haber** (see Figure 1.1) began work on this problem and developed a process for the production of ammonia. Ammonia could be converted to nitrates and used for manufacturing fertilizer. By 1913, with the help of Carl Bosch of the Badische Anilin und Soda Fabrik (BASF), an industrial plant was in operation based on this process (now generally referred to as the **Haber process** but also known as the Haber–Bosch process). This process requires considerable heat and pressure. The reactants must be heated to 1000°F (550°C) and put under 150–200 times normal atmospheric pressure. The equipment necessary to carry out such a reaction can only be made of steel. This reaction is one of the most important industrial chemical processes ever devised, and it would not have been possible without steel.

The life of Fritz Haber also illustrates how the advances of science and technology can be used for good as well as bad. As it turns out, nitrates are a key ingredient of not only fertilizers but also conventional explosives. During World War I, the Germans were cut off from their usual sources of nitrates, and the Haber process was important in supplying the explosives for their munitions during the conflict. Haber was a very patriotic German who did not stop with explosives. A key proponent of the use of poisonous gases on the battlefield during World War I, Haber went to the front and personally supervised the use of these lethal chemicals. After the war, Haber was involved in several projects to support Germany during what was a difficult time for the country. With the rise of the Nazis, however, Haber, who was Jewish by birth, was forced into exile in 1933.

The connection between chemicals and electricity can be seen in the aluminum industry. Before 1886, aluminum was considered a rare and expensive novelty, despite the fact that aluminum was a plentiful component in the Earth's crust. A bar of aluminum was displayed in 1855 at the Paris Exposition next to the Crown jewels. The price of aluminum in 1859 was about $17 per pound, which was about the same price as silver. In 1886, a chemistry student at Oberlin College in Ohio, **Charles Martin Hall**, experimented with methods of extracting aluminum from its ore. The method that this young man developed involved melting the ore and then passing electricity through it. About the same time, a Frenchman named **Paul Héroult** independently developed basically the same process. This basic method, known as the **Hall–Héroult process**, is still used today. Such a procedure is not possible without the availability of large quantities of electricity; therefore, commercial production of aluminum and development of the electric industry go hand in hand. Charles Hall founded the Aluminum Corporation of America (ALCOA) and became a multimillionaire. Héroult became quite wealthy as well and was involved in many ventures in addition to the production of aluminum. Both men died in 1914, within 8 days of each other.

Another hallmark of the second phase of the Industrial Revolution was the tremendous increase in energy consumption. Before the Industrial Revolution, energy consumption was modest and for the most part involved animal, human, or water power. Coal and wood were used mainly for heating. The first phase brought the need to provide fuel for steam engines and iron works. Energy consumption increased even more dramatically in the second phase of the revolution, as everything was done on a massive scale. Energy-intensive steel production began to increase rapidly. The chemical industry churned out all kinds of products that had not been produced before, and most of them required energy for their production. Electricity supplied power easily to all types of functions, some of which either had been done by hand in the past or had not been done at all.

The key locations of the second phase of the Industrial Revolution were also different from the earlier phase. The Industrial Revolution began in England, but the second phase occurred in Germany and the United States, as well as England. These countries became the great powers during the second phase. Before 1860, many of the things that are taken for granted now did not even exist. Some of these items include aspirin (1900), mechanical refrigeration (1861), transportation of frozen meat (1879), the tractor (1898), the airplane (1903), the internal combustion engine (1882), and the diesel engine (1892). The effect of these developments on our lives has been overwhelming.

We now assume that certain conveniences will always be available to us. We expect to have cars, jet planes, dishwashers, clothes washers, air conditioners, packaged food, microwave ovens, and various electric appliances. All of these items consume natural resources, require energy, or produce wastes. Some of them do all three, whereas all of them do at least one of the three. Natural resource consumption, energy consumption, and waste production lead us to the following key questions: "Is our lifestyle sustainable? Can we live this way for a long time?"

1.7 SCIENCE AND THE SCIENTIFIC METHOD

Much of what has been described so far could be described as the history of technology. Contrary to popular belief, science and technology are not the same and in fact have not always been closely related. First, science will be dealt with and then technology. **Science** as we know it is a fairly recent development, which only began to evolve in the 17th century. Originally known as natural philosophy, science took form as scholars began to suggest that theories about nature should be subjected to experimental testing. As will be seen in Chapter 2, when this approach began to be used the resulting insights very quickly led to the reexamination of many long-held ideas.

Science is built around what has come to be known as the **scientific method**. The scientific method comes from the concept that ideas about how the universe functions should be able to be tested to see if the universe actually operates in this way. The scientific method is, in fact, a continuous cycle, and as a result, the method has no beginning and no end. Step 1 is usually given as *defining the problem* for which one wishes to find an understanding. The problem must be of the type that one would expect to understand it better as a result of well-designed experiments. Step 2 is to make a guess about how things function in this problem. This guess is referred to as a **hypothesis** and may be described in some cases as a *model*. Step 3 involves designing and carrying out an *experiment* to see if the hypothesis is correct. The results of this experiment can lead to one of the three outcomes: The experiment might suggest that the hypothesis is correct, that the hypothesis is totally wrong, or that the hypothesis is partly wrong and requires modification. These observations will take us back to step 2, where we keep our hypothesis, abandon it, or modify it. Once the status of our hypothesis is decided, it will again have to be tested by experiment. This is a never-ending process because testing and revision of the hypothesis continue. Even if the experiment agrees with the hypothesis, the process does not end because the next experiment might show that it is incorrect. If a hypothesis is confirmed for the most part repeatedly, then at some point, it may come to be known as a **theory**.

To illustrate how the scientific method works, consider the issue of how smog develops in southern California, a problem discussed further in Chapter 10. Historically, there were several ideas about how the smog was formed. If all of the materials that are found in the polluted air over Los Angeles are put into a box, a toxic mix is obtained, but this mix does not have the same properties as the smog. The problem, then, is, "Why do the gases being put into southern California air not produce the smog usually found in the air when they are put in a box?" Someone eventually surmised that perhaps light is needed to convert the gases to smog. This statement would become the hypothesis. The experiment would be to shine light on a transparent container of the gases. If smog is produced as a result of adding light, then the hypothesis is verified. If smog is not produced, then the hypothesis would be refuted. If the gases change in the presence of light but do not produce something identical to the smog, then the hypothesis may have to be modified. Maybe light and something else are required. A new or revised hypothesis requires more experimentation. Ultimately, this process of questioning, experimenting, answering, and questioning can go on indefinitely.

There are many situations in which one cannot run an experiment in the classical sense but can still apply the logic of the scientific method. Generally, these are fields of study concerning reconstructing the past, experimenting on systems that are so complex as to not be able to be directly tested, or testing systems in which direct experimentation would be considered unethical. In these situations, one tries to state the hypothesis in such a way that data can be collected from current or past situations that occur naturally. Some examples are archaeological findings, ancient gases trapped in polar ice cores, natural occurrences of disease rates under various existing circumstances, and political polling data.

The scientific method cannot be applied everywhere, nor should it be. Some fields of study are based on an approach that is very different from the scientific method. Mathematics, for example, is based on deductive logic. In mathematics, one makes a series of assumptions and then logically deduces whatever follows from those assumptions. Mathematics is not based on the input of empirical data of any kind. Many other fields of study may use empirical data from time to time but not in a systematic manner; that is, they are not data driven. Other issues such as style, reflection on the great thinkers in the field, statements of faith, analysis of the works of others, and argument based on opinion may be somewhat more important than in the study of science. These areas of study are not less valid than science but rather are different ways of knowing. Some fields of study where application of the scientific method is not generally valuable include religion, history, literature, and language studies.

Fields that are data driven and rely on the scientific method are known as the sciences. Based on earlier discussion, science can be defined as the pursuit of knowledge by observation and testing. Fields of study often included in the sciences are physics, chemistry, biology, psychology, sociology, and political science. This list is not exhaustive but mentions some of the major fields.

Usually when we think of science, it is often about **natural science**. Natural science deals with the natural world around us, including biological species; the water, air, and all of the materials of the Earth; the planets of the solar system and their moons; the sun and stars; and the far reaches of space. Most commonly this group of studies includes biology, chemistry, and physics.

1.8 SCIENCE AND TECHNOLOGY

Science and **technology** are closely related in today's society. This chapter has so far discussed science, but now the emphasis will be on technology. Technology dates back to antiquity. Early tools such as the garden hoe are examples of technology. Other examples include cooking, making pottery, extracting metals from their ores, making beer and wine, and extracting drugs from plants. All of these things were carried out before the artisans or practitioners were able to comprehend the scientific principles behind these activities. One excellent definition of technology was given by Hill (1992): "Technology is the sum total of processes by which humans modify the materials of nature to better satisfy their needs and wants."

Although science began to emerge in the 17th century, it was not until the 19th century that humans began seriously to apply science to technology. Since then, inventors and businesspersons have understood the value of applying scientific discoveries to the development of new and better products for humanity (and perhaps their profit margins). Such activities have come to be known as **applied science**. Technology using applied science has developed new drugs, lighter aircraft, hybrid plants, and many other products. Not all of these advances have been in a positive direction, however, as can be seen from the story of Fritz Haber earlier in this chapter. Also, science and technology can be applied, for example, to making chemical warfare weapons and atomic bombs. The problem is that by the middle of the 20th century, the close connection between science and technology had become so commonplace that many people easily confused the two. The distinction between the two fields began to blur. This book focuses on the study of the science of chemistry as it pertains to the environment, but chemical technology is also an important part of this picture.

1.9 SCIENCE AND THE ENVIRONMENT

The environment, broadly, can be construed to include nearly everything on the Earth, both living and nonliving. Biology (which is the study of living things) has always been a focal point of environmental studies because it is the living things and their interactions that define much of the nature of the environment. However, living organisms, whose physical forms are made up of chemicals which must obey the laws of nature, are affected by other substances in the environment, and all substances are chemicals of some type or the other. Additionally, all organisms are themselves made up of chemicals. Clearly, there is a chemical dimension to what goes on in the environment, and it is this aspect of the environment that will be studied.

As we study the chemistry of the environment, we must be aware that science can only tell us certain things. Science can inform us about relationships. Scientists can note that certain chemicals and dead fish in a stream usually occur together. Perhaps science can demonstrate that these chemicals cause the death of fish. Science may be able to suggest ways of keeping the chemicals out of the stream or keeping the fish alive in some other way. *What science cannot do is render value judgments.* The value of fish, the scenic beauty of the wilderness, a microwave oven, a car, a deer, our life, or someone else's life is a judgment made based on our ethical, moral, and religious assumptions. These assumptions are distinct from the science presented here. It is not our intention to make this book totally devoid of personal philosophy, but it is hoped that the scientific facts or theories will be clearly differentiated from personal value judgments.

1.10 ENVIRONMENT AND PUBLIC POLICY

Clearly, as a society, we constantly make value judgments about the environment. We collectively build dams, protect certain species, create national parks, and pass laws against air pollution. Such activities bring environmental studies into the area of public policy, but why does public policy have to intrude itself into environmental issues? In 1968, Garrett Hardin published an article in *Science* entitled "The Tragedy of the Commons." The title of this article is based on a parable introduced in an 1833 pamphlet written by William Lloyd. In the pamphlet, Lloyd discussed the relationship between pastureland that is held in common by everyone ("the commons") and individual herdsmen. Obviously, it was in the best interest of any individual herdsman to graze his livestock on the commons as much as possible, but if everyone did this, then eventually the commons would be overgrazed and would be useless to all. Such a parable is an extremely good paradigm for our times. Many environmental issues can be viewed in this way. The commons can be saved for long-term benefit only if the individuals take their fair share at a fair rate, and it works in the same way with the common resources of the environment. There is often a conflict between the short-term welfare of a few and the long-term welfare of society as a whole. Because most of us do not graze cattle on the commons or anywhere else for that matter, then what are the commons of today? The commons are common resources. These include air, which we all breathe; water, which we all need; and living beings upon which we all depend, such as trees, algae, and fish. It is through public policy that society protects the commons from destruction by selfish individuals. The debate, of course, centers around what exactly should be included as part of the commons, and how it should be protected. Many of the topics in this book lead to such discussions.

Public policy is usually carried out by the authority of the government; however, educational factors, social pressures, economic pressures, and social protests can have an effect. The government usually uses either incentives or penalties. Incentives include encouragements such as tax cuts and payments of money. Such an approach costs the government money, which is often in short supply; therefore, governments usually resort to penalties to stop undesirable activities. These penalties include taxes and fines. There are some other restrictions under which we all operate, but these have nothing to do with the government. These restrictions are the inviolate laws of nature, which are discussed in Chapter 2.

DISCUSSION QUESTIONS

1. At what point did humans cease to be part of "nature" and become separate from their natural surroundings? Must humans have an effect on "nature" just because of their presence or can humans just remain in a natural setting and leave it unaffected?
2. Describe the lives of people who are hunter–gatherers. Also, describe the lives of those engaged in horticulture and agriculture. Compare these three groups with one another.

3. Ancient cities were different from modern cities in many ways but also had some similarities. In what ways were ancient cities similar to modern cities? In what way were they different?
4. Ancient cities were smaller and, therefore, should have had less impact on their environment. Given modern advances in sewage treatment, waste disposal, and other related issues, do modern cities have a greater or smaller impact on the environment than ancient cities? Explain.
5. Compare and contrast life in developed countries of the 21st century with life in Europe before the Industrial Revolution.
6. How were developments in iron production, textile manufacture, and the invention of the steam engine related?
7. In what significant ways did the first phase of the Industrial Revolution differ from the second?
8. Is the term "Industrial Revolution" an appropriate name? Were the changes that occurred more a revolution or an evolution? Why?
9. How does the life of Fritz Haber illustrate some of the moral ambiguities associated with the use of science and technology?
10. Consider this statement: "Today's modern conveniences are detrimental to the well-being of our society." Make an argument supporting this statement. Make an argument opposing this statement.
11. Outline the scientific method and give some of its limitations. Can any subject be studied using the scientific method if one wishes to do so?
12. Explain the difference between science and technology, and suggest why it is that we tend to confuse them in the modern world.
13. What is meant by the "Tragedy of the Commons," and how does it apply to societal issues in our culture?
14. What are some of the measures that governments can take to control the environmentally harmful activities of its citizens? Which ones are used most often and why?

LEARNING OUTCOMES

1. Describe the causes of the replacement of the nomadic lifestyle by farming.
2. State the difference between horticulture and agriculture.
3. Explain the difference between town and cities, and why the latter were generally built near water.
4. Describe the changes brought by Phase I and Phase II of the Industrial Revolution and the roles of key scientists in these developments.
5. Define the scientific method, listing and explaining the steps in the process.
6. Differentiate between science and technology.
7. State the meaning of "The Tragedy of the Commons" and its impact on environmental policy.

GROUP WORK

1. With the class divided into groups of four, prepare to debate discussion question 10 above. Two in your group will argue the affirmative side and two the negative.

2. How much preparation should citizens make for possible shortages such as occurred in the COVID-19 pandemic? What is the difference between preparation and hoarding? How can this be done sustainably (with care for our planet)?
3. Is development in your neighborhood reducing native plants and threatening wildlife? If so, what can/should be done about it? Share your opinions within your group and report back to the class.
4. Think about what you hope to get out of this course. Write down your conclusions and share with your group.

BIBLIOGRAPHY

Bessemer, H., *Sir Henry Bessemer, F.R.S: An Autobiography*, Offices of Engineering, London, 1905, pp. 138–151.

Binczewski, G.J., The point of a monument: a history of the aluminum cap of the Washington monument, *JOM*, 47(11), 20–25, 1995, http://www.tms.org/pubs/journals/JOM/9511/Binczewski-9511.html.

Brain, M., *How Iron and Steel Work*, HowStuffWorks, Atlanta, GA, 2012, http://science.how-stuffworks.com/iron.htm.

Friedrich, B., *Fritz Haber (1868–1934)*, Fritz Haber Institute of the Max Planck Society, Berlin, 2005, http://www.fhi-berlin.mpg.de/history/Friedrich_HaberArticle.pdf.

Garfield, S., One man and his color, *Chemical Heritage*, 24(3), 8–9, 35, 2006.

Geller, T., Aluminum: common metal, uncommon past, *Chemical Heritage*, 25(4), 32–36, 2007/08.

Hardin, G., The tragedy of the commons, *Science*, 162, 1243–1248, 1968.

Hart-Davis, A., *Henry Bessemer, Man of Steel, On-line Science and Technology*, September 1, 1995, http://www2.exnet.com/1995/09/27/science/science.html.

Hill, J.W., *Chemistry for Changing Times*, 6th ed., Macmillan, New York, 1992, p. A37.

Hudson, J., *The History of Chemistry*, Chapman & Hall, New York, 1992.

Isenberg, A.C., Ed., *The Nature of Cities: Culture, Landscape, and Urban Space*, University of Rochester Press, Rochester, NY, 2006.

Macionis, J.H. and Parrillo, V.N., *Cities and Urban Life*, Prentice-Hall, Upper Saddle River, NJ, 2007.

NobelPrize.org, The Nobel Prize in Chemistry 1918: Fritz Haber, in *Nobel Lectures, Chemistry 1901–1921*, Elsevier, Amsterdam, 1966, http://nobelprize.org/nobel_prizes/chemistry/laureates/1918/haber-bio.html.

Background to the Environmental Problem

Bessemer, H. , Sir Henry Bessemer, F.R.S: An Autobiography, Offices of Engineering, London, 1905, pp. 138–151.

Binczewski, G.J. , The point of a monument: a history of the aluminum cap of the Washington monument, JOM, 47(11), 20–25, 1995, http://www.tms.org/pubs/journals/JOM/9511/Binczewski-9511.html.

Brain, M. , How Iron and Steel Work, HowStuffWorks, Atlanta, GA, 2012, http://science.howstuffworks.com/iron.htm.

Friedrich, B. , Fritz Haber (1868–1934), Fritz Haber Institute of the Max Planck Society, Berlin, 2005, http://www.fhi-berlin.mpg.de/history/Friedrich_HaberArticle.pdf.

Garfield, S. , One man and his color, Chemical Heritage, 24(3), 8–9, 35, 2006.

Geller, T. , Aluminum: common metal, uncommon past, Chemical Heritage, 25(4), 32–36,2007/08.

Hardin, G. , The tragedy of the commons, Science, 162, 1243–1248, 1968.

Hart-Davis, A. , Henry Bessemer, Man of Steel, On-line Science and Technology, September 1, 1995, http://www2.exnet.com/1995/09/27/science/science.html.

Hill, J.W. , Chemistry for Changing Times, 6th ed., Macmillan, New York, 1992, p. A37.

Hudson, J. , The History of Chemistry, Chapman & Hall, New York, 1992.

Isenberg, A.C. , Ed., The Nature of Cities: Culture, Landscape, and Urban Space, University of Rochester Press, Rochester, NY, 2006.

Macionis, J.H. and Parrillo, V.N. , Cities and Urban Life, Prentice-Hall, Upper Saddle River, NJ, 2007.

NobelPrize.org, The Nobel Prize in Chemistry 1918: Fritz Haber, in Nobel Lectures, Chemistry 1901–1921, Elsevier, Amsterdam, 1966, http://nobelprize.org/nobel_prizes/chemistry/laureates/1918/haber-bio.html.

The Natural Laws

Hudson, J. , The History of Chemistry, Chapman & Hall, New York, 1992.

Underlying Principles of Chemistry

Chang, R. , Chemistry, 4th ed., McGraw-Hill, New York, 1991, p. 307.

Hill, J.W. , Chemistry for Changing Times, 6th ed., Macmillan, New York, 1992, p. 63.

Hudson, J. , The History of Chemistry, Chapman & Hall, New York, 1992.

Types of Chemical Compounds and Their Reactions

Hudson, J. , The History of Chemistry, Chapman & Hall, New York, 1992.

Joesten, M.D. , Netterville, J.T. , and Wood, J.L. , World of Chemistry: Essentials, Saunders College Publishing, New York, 1993, p. 118.

Element Cycles

Cunningham, W.P. and Saigo, B.W. , Environmental Science, A Global Concern, William C. Brown, Dubuque, IA, 1990, p. 38.

Garrels, R.M. , Mackenzie, F.T. , and Hunt, C. , Chemical Cycles and the Global Environment: Assessing Human Influences, W. Kaufmann, Los Altos, CA, 1975.

Mooney, H.A. , Vitousek, P.M. , and Matson, P.A. , Exchange of materials between terrestrial ecosystems and the atmosphere, Science, 238, 926–932, 1987.

Paasivirta, J. , Chemical Ecotoxicology, Lewis Publishers, Chelsea, MI, 1991.

Sarmiento, J.L. , Ocean carbon cycle, Chemical and Engineering News, 71(22), 30–43, 1993.

Vaccari, D.A. , Phosphorus: a looming crisis, Scientific American, 300(6), 54–59, 2009.

Vitousek, P.M. , Aber, J. , Howarth, R.W. , Likens, G.E. , Matson, P.A. , Schindler, D.W. , Schlesinger, W.H. , and Tilman, G.D. , Human alteration of the global nitrogen cycle: causes and consequences, Issues in Ecology, August 30, 2000, http://esa.sdsc.edu/til-man.htm.

Toxicology

Ames, B.N. and Gold, L.S. , Cancer prevention and the environmental chemical distraction, in Politicizing Science: The Alchemy of Policymaking, Gough, M. , Ed., Hoover Institute Press, Stanford, CA, 2003, pp. 117–142.

Anon. , The Beaver Fur Hat – The Fashion of Europe, White Oak Society, Deer River, MN, 2001, http://www.whiteoak.org/historical-library/fur-trade/the-beaver-fur-hat/.

Anon. , Dioxin poisoning scars Ukrainian presidential candidate, Environmental News Service, December 13, 2004, http://www.ens-newswire.com/ens/dec2004/2004-12-13-03.asp.

Call2Recycle® , http://www.call2recycle.org.

Clark, P. , Tennessee Reclamation Project: More Lessons Learned for the New Millennium, BlueRidgeHighlander.com, http://www.theblueridgehighlander.com/polk_county_tennessee/reclamation_project/index.html.

Clayton, R. , Endocrine Disruptors in the Environment: A Review of Current Knowledge, 2nd ed., Foundation for Water Research, Buckinghamshire, UK, 2002.

Corrosion Doctors , Mad as a Hatter, http://www.corrosion-doctors.org/Elements-Toxic/Mercury-mad-hatter.htm.

Crummett, W.B. , Decades of Dioxin: Limelight on a Molecule, Xlibris Corporation, Bloomington, IN, 2002.

Damstra, T. , Barlow, S. , Bergman, A. , Lavlock, R. , and Van Der Kraak, G. , Eds., Global Assessment of the State-of-the-Science of Endocrine Disruptors, prepared on behalf of World Health Organization, International Labour Organisation, and United Nations Environment Programmme, World Health Organization, Geneva, 2002.

DES Cancer Network , Timeline: A Brief History of DES (Diethylstilbesterol), DES CancerNetwork, http://www.descancer.org/timeline.html.

Hileman, B. , Yushchenko poisoning, Chemical and Engineering News, 82(51), 13, 2004.

Hill, J.W. , Chemistry for Changing Times, Macmillan, New York, 1992, p. 735.

Hodgson, E. , A Textbook of Modern Toxicology, Wiley, Hoboken, NJ, 2004.

Kungolos, A.G. , Brebbia, C.A. , Samaras, C.P. , and Popov, V. , Eds., Environmental Toxicology, WIT Press, Southampton, UK, 2006.

Landis, W.G. and Yu, M.-H. , Introduction to Environmental Toxicology: Impacts of Chemicals upon Ecological Systems, Lewis Publishers, Boca Raton, FL, 2004.

Langmuire, A.D. and Nathanson, N. , The Cutter Incident: Poliomyelitis Following Formaldehyde-Inactivated Poliovirus Vaccination in the United States During the Spring of 1955. II. Relationship of Poliomyelitis to Cutter Vaccine, American Journal of Epidemiology, 109–140, 1995, doi: 10.1093/oxford journals.aje.a117611.

Liska, Ken , Drugs and the Human Body with Implications for Society, Seventh ed., Pearson Prentice Hall, Upper Saddle River, NJ, 2004.

Paasivirta, J. , Chemical Ecotoxicology, Lewis Publishers, Chelsea, MI, 1991.

Quinion, M. , Mad as a Hatter, World Wide Words, March 3, 2001, http://www.worldwide-words.org/qa/qa-mad2.htm.

Ritter, L. , Solomon, K.R. , Forget, J. , Stemeroff, M. , and O'Leary, C. , Persistent Organic Pollutants, An Assessment Report on: DDT-Aldrin-Dieldrin-Chlordane-Heptachlor-Hexachlorobenzene-Mirex-Toxaphene, Polychlorinated Biphenyls, Dioxins and Furans, The International Programme on Chemical Safety, World Health Organization, Geneva, 1995.

Ritter, S. , Bisphenol A, Chemical and Engineering News, 89(23), 13–22, 2011.

Van Patten, P. , The Mad Hatter mercury mystery, Wrack Lines, 2(1), 13–16, 2002.

Wright, P. , Nitric Oxide: From Menace to Marvel of the Decade, briefing document prepared for the Royal Society and Association of British Science Writers, May 1996.

Traditional Energy Sources and Modern Society

Anon. , Matters of scale – hubris on the Yangtze, World Watch Magazine, 16(6), 2003, http://www.worldwatch.org/node/795.

Barta, P. and Spencer, J. , Crude awakening as alternative energy heats up, environmental concerns grow, The Wall Street Journal, December 5, 2006, p. A1.

Bentley, R.W. , Global oil and gas depletion – an overview, Energy Policy, 30, 189–205, 2002.

BP , Statistical Review, BP, 2011, http://www.bp.com/statisticalreview.

Brown, L.R. , Exploding U.S. Grain Demand for Automotive Fuel Threatens World Food Security and Political Stability, Earth Policy Institute, Washington, DC, https://www.feasta.org/documents/feastareview/campbell.htm 2006, http://www.earth-policy.org/Updates/2006/Update60.htm.

Brown, L.R. , Supermarkets and Service Stations Now Competing for Grain, Earth Policy Institute, Washington, DC, 2006, http://www.earth-policy.org/Updates/2006/Update55.htm.

Bui, Q. , History of Gasoline Prices in the United States, Stanford University, Stanford, CA, 2010, http://large.stanford.edu/courses/2010/ph240/bui1/.

Campbell, C.J. , The Imminent Peak of World Oil Production, presentation to a House of Commons All-Party Committee, London, July 7, 1999, https://www.feasta.org/documents/feastareview/campbell.htm

Campbell, C.J. and Laherrère, J.H. , The end of cheap oil, Scientific American, 278(3), 78–83, 1998.

Canine, C. , How to clean coal, OnEarth, Fall, 27, 21–29, 2005.

China Three Gorges Project Corporation , History, China Three Gorges Project Corporation, Yichang, China, 2002 (http://www.ctgpc.com/history/history_a.php).

Cunningham, W.P. and Saigo, B.W. , Environmental Science – A Global Concern, 2nd ed., Wm. C. Brown, Dubuque, IA, 1992, pp. 375, 380.

Deffeyes, K.S. , When Oil Peaked – Hubbert's Peak in the 21st Century, 2011, http://www.princeton.edu/hubbert/the-peak.html.

Deutch, J. , Ansolabehere, S. , Driscoll, M. , Gray, P.E. , Holdren, J.P. , Joshow, P.L. , Lester, R.K. , Moniz, E.J. , and Todreas, N.E. , Eds., The Future of Nuclear Power – An Interdisciplinary MIT Study, Massachusetts Institute of Technology, Cambridge, MA, 2003.

Deutch, J. , Forsberg, C. , Kadak, A. , Kazimi, M. , Moniz, E. , and Parsons, J. , Eds., Update of the MIT 2003 Future of Nuclear Power, Massachusetts Institute of Technology, Cambridge, MA, 2009.

Deutch, J. , Kanter, A. , Moniz, E. , and Poneman, D. , Making the world safe for nuclear energy, Survival, 46(4), 65–80, 2004–2005.

Farrell, A.E. , Plevin, R.J. , Turner, B.T. , Jones, A.D. , O'Hare, M. , and Kammen, D.M. , Ethanol can contribute to energy and environmental goals, Science, 311(5760), 506–508, 2006.

FERC , A Guide to LNG – What All Citizens Should Know, Office of Energy Projects, Federal Energy Regulatory Commission, Washington, DC, 2005.

Fickett, J.W. , US Natural Gas Reserves, ClearOnMoney.com , June 21, 2012, http://www.clearonmoney.com/dw/doku.php?id=public:--us_natural_gas_reserves.

Geller, H.S. , Energy Revolution – Policies for a Sustainable Future, Island Press, Washington, DC, 2003.

Goodell, J. , Big Coal – The Dirty Secret Behind America's Energy Future, Houghton Mifflin, Boston, MA, 2006.

Griffiths, D. , Three Gorges Dam reaches for the sky, BBC News, May 19, 2006, http://news.bbc.co.uk/2/hi/asia-pacific/4998740.stm.
Hebert, H.J. , Study – ethanol won't solve energy problems, USA Today, July 10, 2006, http://www.usatoday.com/tech/news/2006–07-10-ethanol-study_x.htm.
Hess, G. , EPA probes fracking impact on water, Chemical and Engineering News, 89(46), 29, 2011.
Johnson, J. , EPA issues fracking rules, Chemical and Engineering News, 90(17), 7, 2012.
Johnson, J. , Federal rules for fracking, Chemical and Engineering News, 90(20), 8, 2012.
Johnson, J. , Methane – a new 'fracking' fiasco, Chemical and Engineering News, 90(16), 34–37, 2012.
Johnson, J. , No more Yucca Mountain, Chemical and Engineering News, 90(7), 33–34, 2012.
Johnson, J. , Nuclear returns, Chemical and Engineering News, 90(8), 10, 2012.
Kemsley, J.N. , Nuclear efficiency, Chemical and Engineering News, 88(37), 29–31, 2010.
Liu, Y. , Chinese Biofuels Expansion Threatens Ecological Disaster, Worldwatch Institute, Washington, DC, 2007, http://www.worldwatch.org/node/4959.
Maine SPO , A brief history of the Edwards Dam, Maine State Planning Office, Maine.gov , 2013, http://www.state.me.us/spo/sp/edwards/history.php.
McElroy, M.B. , The ethanol illusion, Harvard Magazine, 33–35, 107, 2006.
McGivering, J. , Three Gorges Dam's social impact, BBC News, May 20, 2006, http://news.bbc.co.uk/2/hi/asia-pacific/5000198.stm.
McMahon, T. , Ed., Historical oil prices chart, InflationData.com , June 14, 2012, http://inflationdata.com/inflation/inflation_rate/Historical_Oil_Prices_Chart.asp.
Miller, G.T. , Living in the Environment – An Introduction to Environmental Science, 6th ed., Wadsworth, Belmont, CA, 1990, p. 426.
Mooney, C. , The truth about fracking, Scientific American, 305(5), 80–85, 2011.
National Biodiesel Board , What is biodiesel?, Biodiesel.org , 2013, http://www.biodiesel.org/what-is-biodiesel.
Natural Gas Supply Organization , Natural gas supply, NaturalGas.org , 2011, http://www.naturalgas.org/business/supply.asp.
Natural Gas Supply Organization , You've Got Shale - the "Where" and "What" of Shale Gas Formations, NaturalGas.org , 2011, http://naturalgas.org/shale/gotshale.asp.
NEI , Nuclear Energy – Just the Facts, Nuclear Energy Institute, Washington, DC, 2012, http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/brochures/justthefacts.
NEI , World Statistics – Nuclear Energy Around the World, Nuclear Energy Institute, Washington, DC, 2012, http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics/.
NEI , How It Works – Electric Power Generation, Nuclear Energy Institute, Washington, DC, 2013, http://www.nei.org/howitworks/electricpowergeneration/.
NHA , Hydro Facts, National Hydropower Association, Washington, DC, 2021. http://www.hydro.org/hydrofacts/factsheets.php.
NIOSH , Coal Workers' Pneumoconiosis – Black Lung Benefits, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Atlanta, GA, 2008, http://www2a.cdc.gov/drds/WorldReportData/FigureTableDetails.asp?FigureTableID=527&GroupRefNumber=T02-13.
Palha, S. , The emerging natural gas crisis, SafeHaven.com, 2006, http://www.safehaven.com/showarticle.cfm?id=6252.
Petkewich, R.A. , Fluorescent bulbs trade off energy savings for mercury, Chemical and Engineering News, 86(41), 29, 2008.
Pimentel, D. and Patzek, T. , Green plants, fossil fuels, and now biofuels, BioScience, 56(11), 875, 2006.
Piore, A. , Planning for the black swan, Scientific American, 304(6), 48–53, 2011.
Ponseti, M. and Lopez-Pujol, J. , The Three Gorges Dam Project in China: History and Consequences, Revista HMiC, numero IV, 151-188, 2006.
REN21 , Global Status Report, Renewable Energy Policy Network for the 21st Century, Paris, 2010.

Sawin, J.L. , Mastny, L. , Aeck, M.H. , Hunt, S. , MacEvitt, A. , Stair, P. , Cohen, A.U. , Hendricks, B. , and Mohin, T. , American Energy – The Renewable Path to Energy Security, Worldwatch Institute and Center for American Progress, Washington, DC, 2006.

Seward, G.P. , How long will global uranium deposits fuel the world's nuclear reactors at present consumption rates?, Scientific American, 300(3), 84, 2009.

Sperling, D. and Cannon, J.S. , Driving Climate Change – Cutting Carbon from Transportation, Academic Press, Amsterdam, 2007.

Swenson, R. , The *Coming Global Oil Crisis: Natural Gas* , http://www.hubbertpeak.com/gas/.

Tro, N. , Chemistry: A Molecular Approach, Fifth ed., Pearson Publishing, Upper Saddle River, NJ, 2020, p. 965.

USDOE , Biodiesel Handling and Use Guidelines, 3rd ed., DOE/GO-102006-2358, National Renewable Energy Laboratory, U.S. Department of Energy, Washington, DC, 2006, http://www.nrel.gov/docs/fy06osti/40555.pdf.

USDOL , Coal Fatalities for 1900 through 2011, Mine Safety and Health Administration, U.S. Department of Labor, Arlington, VA, 2012, http://www.msha.gov/stats/centurystats/coalstats.asp.

USEIA , Natural Gas Imports, Exports, and Net Imports, Selected Years, 1949–2011, U.S. Energy Information Administration, Washington, DC, 2011, http://www.eia.gov/totalenergy/data/annual/pdf/sec6_9.pdf.

USEIA , Natural Gas Overview, Selected Years, 1949–2010, U.S. Energy Information Administration, Washington, DC, 2011, http://www.eia.gov/totalenergy/data/annual/pdf/sec6_5.pdf.

USEIA , Retail Motor Gasoline and On-Highway Diesel Fuel Prices, 1949–2010, U.S. Energy Information Administration, Washington, DC, 2011, http://www.eia.gov/totalenergy/data/annual/pdf/sec5_59.pdf.

USEIA , Electricity Explained – Electricity in the United States – Basics, U.S. Energy Information Administration, Washington, DC, 2021 http://www.eia.gov/energyex-plained/electricity.

USEIA , Natural Gas Explained – Use of Natural Gas, U.S. Energy Information Administration, Washington, DC, 2012, http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_use.

USEIA , Electricity in the U.S., U.S. Energy Information Administration, Washington, DC, 2020.

Von Hippel, F.N. , Rethinking Nuclear Fuel Recycling, Scientific American, 298(5), 88–93, 2008.

Wald, M.L. , The power of renewables, Scientific American, 300(3), 56–61, 2009.

Wald, M.L. , What now for nuclear waste?, Scientific American, 301(2), 46–53, 2009.

What Is Decay Heat? Explanation of Nuclear Reactor Decay Heat, Nuclear Science and Engineering at MIT, Cambridge, MA, 2011, http://mitnse.com/2011/03/16/what-is-decay-heat/.

WNA , World Nuclear Power Reactors & Uranium Requirements, World Nuclear Association, London, 2012, http://www.world-nuclear.org/info/reactors.html.

WNA , Fukushima Accident 2011, World Nuclear Association, London, 2013, http://www.world-nuclear.org/info/fukushima_accident_inf129.html.

Emerging Energy Sources and Modern Society

Anon. , Potential for US Wind Energy is 10.5 GW, *RenewableEnergyFocus.com* , 2010, http://www.renewableenergyfocus.com/view/7446/potential-for-us-wind-energy-is-10-5-gw/.

, Hydrogen fuel cell cars: everything you need to know, 2020. https://www.bmw.com/en/innovation/how-hydrogen-fuel.

Barta, P. and Spencer, J. , Crude awakening as alternative energy heats up, environmental concerns grow, *The Wall Street Journal*, December 5, 2006, p. A1.

Brown, L.R. , Exploding U.S. Grain Demand for Automotive Fuel Threatens World Food Security and Political Stability, Earth Policy Institute, Washington, DC, 2006, http://www.earth-policy.org/plan_b_updates/2006/update60/.

Brown, L.R. , Supermarkets and Service Stations Now Competing for Grain, Earth Policy Institute, Washington, DC, 2006, http://www.earth-policy.org/mobile/releases/update55.

Cunningham, W.P. and Saigo, B.W. , Environmental Science: A Global Concern, 2nd ed., Wm. C. Brown, Dubuque, IA, 1992, pp. 375, 380.

Davidson, R. , Cape Wind: requiem for a dream, Wind Power Monthly, May 1, 2018.
Dickson, M.H. and Fanelli, M. , What Is Geothermal Energy?, International Geothermal Association, Bochum, 2004, https://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55))/reference/ReferencesPapers.aspx?ReferenceID=1741677
ETE Energy World, March 18, 2019.
Farrell, A.E. , Plevin, R.J. , Turner, B.T. , Jones, A.D. , O'Hare, M. , and Kammen, D.M. , Ethanol can contribute to energy and environmental goals, Science, 311(5760), 506–508, 2006.
Geller, H.S. , Energy Revolution: Policies for a Sustainable Future, Island Press, Washington, DC, 2003.
Goodell, J. , Big Coal: The Dirty Secret behind America's Energy Future, Houghton Mifflin, Boston, MA, 2006.
Gupta, R.B. , Ed., Hydrogen Fuel: Production, Transport, and Storage, CRC Press, Boca Raton, FL, 2009.
Hebert, H.J. , Study: ethanol won't solve energy problems, USA Today, July 10, 2006, http://www.usatoday.com/tech/news/2006-07-10-ethanol-study_x.htm.
Kennedy, J.H. , Cape Wind clears hurdle to Nantucket Sound wind project, Vineyard Gazette, December 30, 2011, http://www.mvgazette.com/article.php?33411.
Liu, Y. , Chinese Biofuels Expansion Threatens Ecological Disaster, Worldwatch Institute, Washington, DC, 2007, http://www.worldwatch.org/node/4959.
McElroy, M.B. , The ethanol illusion, Harvard Magazine, 33–35, 107, 2006.
McMahon, T. , Ed., Historical oil prices chart, InflationData.com , June 14, 2012, http://inflationdata.com/inflation/inflation_rate/Historical_Oil_Prices_Chart.asp.
Miller, G.T. , Living in the Environment: An Introduction to Environmental Science, 6th ed., Wadsworth, Belmont, CA, 1990, p. 426.
National Biodiesel Board , What is biodiesel?, Biodiesel.org , 2013, http://www.biodiesel.org/what-is-biodiesel.
Nice, K. , How Stirling engines work, Howstuffwork. https://auto.howstuffworks.com/stirling-engine.htm
Petkewich, R.A. , Fluorescent bulbs trade off energy savings for mercury, Chemical and Engineering News, 86(41), 29, 2008.
Pimentel, D. and Patzek, T. , Green plants, fossil fuels, and now biofuels, BioScience, 56(11), 875, 2006.
REN21 , Global Status Report, Renewable Energy Policy Network for the 21st Century, Paris, 2010.
Romm, J.J. , The Hype about Hydrogen: Fact and Fiction in the Race to Save the Climate, Island Press, Washington, DC, 2004.
Sawin, J.L. , Mastny, L. , Aeck, M.H. , Hunt, S. , MacEvitt, A. , Stair, P. , Cohen, A.U. , Hendricks, B. , and Mohin, T. , American Energy: The Renewable Path to Energy Security, Worldwatch Institute and Center for American Progress, Washington, DC, 2006.
Sperling, D. and Cannon, J.S. , Driving Climate Change: Cutting Carbon from Transportation, Academic Press, Amsterdam, 2007.
Solar Power Europe , Global Market Outlook for Solar Power 2017–2021, 2019.
Tracy, D. , Has solar push lost its luster? Orlando Sentinel, December 24, 2006.
Union of Concerned Scientists , Clean Energy: How Hydrokinetic Works, Union of Concerned Scientists, Cambridge, MA, 2008, http://www.ucsusa.org/clean_energy/renewable_energy_basics/how-hydroelectric-energy-works.html.
USDOE , Biodiesel Handling and Use Guidelines, 3rd ed., DOE/GO-102006-2358, National Renewable Energy Laboratory, U.S. Department of Energy, Washington, DC, 2006, http://www.nrel.gov/docs/fy06osti/40555.pdf.
USDOE , Alternative Fueling Station Total Counts by State and Fuel Type, Alternative Fuels Data Center, U.S. Department of Energy, Washington, DC, 2012, http://www.afdc.energy.gov/fuels/stations_counts.html.
USDOE , Clean Cities 2012 Vehicle Buyer's Guide, DOE/GO-102012-3314, National Renewable Energy Laboratory, U.S. Department of Energy, Washington, DC, 2012.
USDOE , Hybrid Electric Vehicles, Alternative Fuels Data Center, U.S. Department of Energy, Washington, DC, 2012, http://www.afdc.energy.gov/afdc/vehicles/electric_basics_hev.html.

1. USDOE , Installed Wind Capacity, U.S. Department of Energy, Washington, DC, 2012, https://windexchange.energy.gov/maps-data/321https://windexchange.energy.gov/maps-data/321
USDOE , Maps and Data, Alternative Fuels and Data Center, U.S. Department of Energy, Washington, DC, 2012, http://www.afdc.energy.gov/data/%23tab/all.
USDOE , Plug-In Hybrid Electric Vehicles, Alternative Fuels and Data Center, U.S. Department of Energy, Washington, DC, 2012, http://www.afdc.energy.gov/afdc/vehicles/electric_basics_phev.html.
USDOE , Energy Savers: Tips on Saving Energy & Money at Home, Energy.gov, U.S. Department of Energy, Washington, DC, 2013, https://www.energy.gov/sites/prod/files/energy_savers.pdf
USDOE , Sunshot, U.S. Department of Energy, Washington, DC, 2013, http://www1.eere.energy.gov/solar/sh_basics_water.html.
USEIA Electricity Explained , Electricity in the United States, March 20, 2020.
Velasquez-Manoff, M. , Surprise: not-so-glamorous conservation works best, The Christian Science Monitor, November 30, 2006, https://www.csmonitor.com/2006/1130/p13s01-sten.html.
Wald, M.L. , The power of renewables, Scientific American, 300(3), 56–61, 2009.

Weather and Climate

Ahrens, C.D. , Meteorology Today: An Introduction to Weather, Climate, and the Environment, West Publishing Company, St. Paul, MN, 1994, pp. 58, 59, 232.
Christianson, G.E. , Greenhouse: The 200-Year Story of Global Warming, Walker & Company, New York, 1999.
Cunningham, W.P. and Saigo, B.W. , Environmental Science: A Global Concern, Wm. C. Brown, Dubuque, IA, 1990, pp. 289, 318–320.
Diamond, J. , Collapse, Penguin Books, London, 2005.
Hileman, B. , Web of interactions makes it difficult to untangle global warming data, Chemical and Engineering News, 70(17), 7–19, 1992.
Lorius, C. , Jouzel, J. , Raynaud, D. , Hansen, J. , and LeTreut H. , The ice-core record: climate sensitivity and future greenhouse warming data, Nature, 347(6289), 139–145, 1990.
Lutgens, F.K. and Tarbuck, E.J. , The Atmosphere, Prentice-Hall, Upper Saddle River, NJ, 2007.
Schneider, S.H. , The changing climate, Scientific American, 261(3), 70–79, 1989.
Schoen, D. , Learning from polar ice core research, Environmental Science and Technology, 33(7), 160A–163A, 1999.

Air Quality

Altshuller, A.P. and Bufalini, J.J. , Photochemical aspects of air pollution: a review, Environmental Science & Technology, 5(1), 39–64, 1971.
Brimblecombe, P. , The Big Smoke: A History of Air Pollution in London Since Medieval Times, Methuen, London, 1987.
Bufalini, M. , Oxidation of sulfur dioxide in polluted atmospheres: a review, Environmental Science & Technology, 5(8), 685–700, 1971.
Bunce, N. , Environmental Chemistry, 2nd ed., self-published, Guelph, ON, 1994, p. 161.
Chang, R. , Chemistry, 4th ed., McGraw-Hill, New York, 1991, p. 661.
Enger, E.D. , Lormelink, J.R. , Smith, B.F. , and Smith, R.J. , Environmental Science: The Study of Interrelationships, 3rd ed., Wm. C. Brown, Dubuque, IA, 1989, p. 400.
Manahan, S.E. , Environmental Chemistry, Lewis Publishers, Chelsea, MI, 1991, p. 324.
National Atmospheric Deposition Program , NTN Maps, 2012, http://nadp.sws.uiuc.edu/ntn/maps.aspx.

National Atmospheric Deposition Program , NTN Maps, 2018, http://nadp.slh.wisc.edu/maplib/pdf/2018/pH_2018.pdf.
USEPA , Acid Rain and Related Programs: 2007 Progress Report, EPA-430-R-08-010, U.S. Environmental Protection Agency, Washington, DC, 2009.
USEPA , NOx Budget Trading Program: Basic Information, U.S. Environmental Protection Agency, Washington, DC, 2009, http://www.epa.gov/airmarkets/progsregs/nox/sipba-sic.html.
USEPA, 2014 Program Progress Clean Air Interstate Rule, Acid Rain Program, and Former NOX Budget Trading Program , U.S. Environmental Protection Agency, Washington, DC, 2014. https://www.epa.gov/airmarkets/nox-budget-trading-program-historical-reports
USEPA , National Ambient Air Quality Standards (NAAQS), U.S. Environmental Protection Agency, Washington, DC, 2011, http://epa.gov/air/criteria.html.
USEPA , NOx Budget Trading Program Historical Reports, U.S. Environmental Protection Agency, Washington, DC, 2012, https://www.epa.gov/airmarkets/nox-budget-trading-program-historical-reports
USEPA , Regulatory Impact Analysis for the Final Clean Air Interstate Rule,, U.S. Environmental Protection Agency, Washington, DC, 2021. https://www.epa.gov/airmarkets/regulatory-impact-analysis-final-clean-air-interstate-rule
USEPA, Overview of the Cross-State Air Pollution Rule , U.S. Environmental Protection Agency, Washington, DC, 2021, https://www.epa.gov/csapr/overview-cross-state-air-pollution-rule-csapr
USEPA , The Plain English Guide to the Clean Air Act, U.S. Environmental Protection Agency, Washington, DC, 2012, http://www.epa.gov/air/peg/.
USEPA , Power Plant Emission Trends, U.S. Environmental Protection Agency, Washington, DC, 2020, https://www.epa.gov/airmarkets/power-plant-emission-trends.

Indoor Air Quality

ALA , Lung Cancer Causes & Risk Factors, American Lung Association, 2021, https://www.lung.org/lung-health-diseases/lung-disease-lookup/lung-cancer/learn-about-lung-cancer/what-causes-lung-cancer.
Anderson, D.J. and Hites, R.A. , Chlorinated pesticides in indoor air, Environmental Science & Technology, 22(6), 717–720, 1988.
Austin, B.S. , Greenfield, S.M. , Weir, B.R. , Anderson, G.E. , and Behar, J.V. , Modeling the indoor environment, Environmental Science & Technology, 26(5), 851–858, 1992.
Baker, R.R. and Protor, C.J. , The origins and properties of environmental tobacco smoke, Environment International, 16, 231–245, 1990.
Brody, A.R. , Samuels, S.W. , Nicholson, W.J. , Johnson, E.M. , Harington, J.S. , Melius, J. , Landrigan, P.J. , and Crump, K.S. , Series of four letters on “asbestos, carcinogenicity, and public policy”, Science, 248, 795–799, 1990.
Brooks, B.O. and Davis, W.F. , Understanding Indoor Air Quality, CRC Press, Boca Raton, FL, 1992, p. 39.
Bunce, N. , Environmental Chemistry, 2nd ed., self-published, Guelph, Ontario, Canada, 1994, p. 116.
Jaakkola, J.J.K. , Reinikainen, L.M. , Heinonen, O.P. , Majanen, A. , and Seppanen, O. , Indoor air quality requirements for healthy office buildings: recommendations based on an epidemiologic study, Environment International, 17, 371–378, 1991.
Janerich, D.T. , Thompson, W.D. , Varela, L.R. , Greenwald, P. , Chorost, S. , Tucci, C. , Zaman, M.B. , Melamed, M.R. , Kiely, M. , and McKneally, M.F. , Lung cancer and exposure to tobacco smoke in the household, New England Journal of Medicine, 323(10), 632–636, 1990.
Kuller, L.H. , Garfinkel, L. , Correa, P. , Haley, N. , Hoffmann, D. , Preston-Martin, S. , and Sandler, D. , Contribution of passive smoking to respiratory cancer, Environmental Health Perspectives, 70, 57–69, 1986.
Löfroth, G. , Burton, R.M. , Forehand, L. , Hammond, S.K. , Seila, R.L. , Zweidinger, R.B. , and Lewtas, J. , Characterization of environmental tobacco smoke, Environmental Science & Technology, 23(5), 610–614, 1989.

Schaefer, V.J. , Mohnen, V.A. , and Veirs, V.R. , Air quality of American homes, Science, 175, 173–175, 1972.
Sexton, K. , Petreas, M.X. , and Liu, K.-S. , Formaldehyde exposure inside mobile homes, Environmental Science & Technology, 23(8), 985–988, 1989.
Somersall, A.C. and Natural Wellness Group, Fresh Air for Life: How to Win Your Unseen War against Indoor Air Pollution, Natural Wellness Group, Toronto, Ontario, Canada, 2006.
USCPSC , What You Should Know about Space Heaters, U.S. Consumer Product Safety Commission, Washington, DC, 2001.
USDHHS , Toxicological Profile for Asbestos, U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA, 2001.
USDHHS , The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General – Executive Summary, Public Health Service, U.S. Department of Health and Human Services, Rockville, MD, 2006.
USEPA , Candles and Incense as Potential Sources of Indoor Air Pollution: Market Analysis and Literature Review, EPA 600/R-01-001, U.S. Environmental Protection Agency, Washington, DC, 2001.
USEPA , A Citizen’s Guide to Radon, EPA 402-K02-006, U.S. Environmental Protection Agency, Washington, DC, 2005.
USEPA , Consumer’s Guide to Radon Reduction, EPA 402-K-06-094, U.S. Environmental Protection Agency, Washington, DC, 2006.
USEPA , Care for Your Air: A Guide to Indoor Air Quality, EPA 402/F-08/008, U.S. Environmental Protection Agency, Washington, DC, 2008.
USEPA , Respiratory Health Effects of Passive Smoking (Also Known as Secondhand Smoke or Environmental Tobacco smoke ETS, U.S. Environmental Protection Agency, Washington, DC, 2021, https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2835.
USEPA , The Inside Story: A Guide to Indoor Air Quality, U.S. Environmental Protection Agency, Washington, DC, 2012, http://www.epa.gov/iaq/pubs/insidestory.html.
USEPA , Why Is Radon the Public Health Risk That It Is?, U.S. Environmental Protection Agency, Washington, DC, 2012, http://www.epa.gov/radon/aboutus.html.
USEPA , How Much Ventilation Do I Need in My Home to Improve Indoor Air Quality?, EPA, 2019, https://www.epa.gov/indoor-air-quality-iaq/how-much-ventilation-do-i-need-my-home-improve-indoor-air-quality.
USEPA , Respiratory Health Effects of Passive Smoking (Also Known as Exposure to Secondhand Smoke or Environmental Tobacco Smoke ETS), Risk Assessment Portal, records display, September 30, 2020, https://cfpub.epa.gov.

Global Atmospheric Change

Adger, N . et al. and Members of Working Group II of the IPCC , Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability – Summary for Policymakers, Fourth Assessment Report, Intergovernmental Panel on Climate Change, Geneva, 2007.
Alley, R . et al. and Members of Working Group I of the IPCC , Climate Change 2007: The Physical Science Basis – Summary for Policymakers, Fourth Assessment Report, Intergovernmental Panel on Climate Change, Geneva, 2007.
Butler, J.H. , Radiative Climate Forcing by Long-Lived Greenhouse Gases: The NOAA Annual Greenhouse Gas Index (AGGI), Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO, 2012, http://www.cmdl.noaa.gov/aggi/.
Butler, J.H. , and Montzka, S.A. , The NOAA Annual Greenhouse Gas Index (AGGI), Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO, 2019, http://www.esrl.noaa.gov/gmd/aggi.html. Last accessed in 2013 .
CCSP , Methane as a Greenhouse Gas, CCSP-H1, U.S. Climate Change Science Program, Washington, DC, 2006, http://www.climatescience.gov/infosheets/highlight1/CCSP-H1-methane18jan2006.pdf.
CNBC , Biden Will Rejoin the Paris Climate Accord. Here’s What Happens Next, November 20, 2020. https://www.cnbc.com/2020/11/20/biden-to-rejoin-paris-climate-accord-heres-what-happens-next-.html.

Dlugokencky, E.J. , Houweling, S. , Bruhwiler, L. , Masarie, K.A. , Lang, P.M. , Miller, J.B. , and Tans, P.P. , Atmospheric methane levels off: temporary pause or a new steady-state?, Geophysical Research Letters, 30(19), 5.1–5.4, 1992.

King, D. , Richards, K. , and Tyldesey, S. , International Climate Change Negotiations: Key Lessons and Next Steps, Smith School of Enterprise and the Environment, University of Oxford, Oxford, 2011, http://www.smithschool.ox.ac.uk/wp-content/uploads/2011/03/Climate-Negotiations-report_Final.pdf.

NASA , Total Ozone Mapping Spectrometer, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD, 2012.

NOAA , Ozone Depletion, Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO, http://www.esrl.noaa.gov/gmd/about/ozone.html. Last accessed in 2013

NOAA , Trends in Atmospheric Carbon Dioxide, Global Monitoring Division, Earth System Research Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO, 2019, http://www.esrl.noaa.gov/gmd/ccgg/trends/co2_data_mlo.html.

Schneider, S.H. , Global Warming, Sierra Club Books, San Francisco, CA, 1989, p. 100.

Solomon, S . et al., Eds., Climate Change 2007: The Physical Science Basis, Intergovernmental Panel on Climate Change, Geneva, 2007.

Todaro, R.M. , Ed., Stratospheric Ozone: An Electronic Textbook, Atmospheric Chemistry and Dynamics Branch, Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD, 2003,http://www.ccpo.odu.edu/SEES/ozone/oz_class.htm.

UNFCCC , Cancun Agreements: Main Objectives of the Agreement, United Nations Framework Convention on Climate Change, Bonn, 2010, http://cancun.unfccc.int/cancun-agreements/main-objectives-of-the-agreements/2013.

UNFCCC , Cancun Agreements: Significance of the Key Agreements Reached at Cancun, United Nations Framework Convention on Climate Change, Bonn, 2010, https://unfccc.int/significance-of-the-key-agreements-reached-at-cancun/2013.

UNFCCC , Report of the Conference of the Parties on Its Fifteenth Session, held in Copenhagen from 7 to 19 December 2009, United Nations Framework Convention on Climate Change, Bonn, 2010, http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf.

USEPA , Climate Change Indicators in the United States, U.S. Environmental Protection Agency, Washington, DC, 2006, http://epa.gov/climatechange/science/recentslc.html.

USEPA , Maps of lands vulnerable to sea level rise: Gulf Coast, 2000, Risingsea.net, http://papers.risingsea.net/coarse-sea-level-rise-maps-gulf.html.

Watson, R.T. et al., Climate Change 2001: Synthesis Report – Summary for Policymakers, Intergovernmental Panel on Climate Change, Geneva, 2001.

WHO , Global Solar UV Index: A Practical Guide, World Health Organization, Geneva, 2002.

Zurer, P.S. , Ozone depletion’s recurring surprises challenge atmospheric scientists, Chemical & Engineering News, 71(21), 9, 1993.

Water

Arms, K. , Environmental Science, Saunders, New York, 1990, p. 217.

Buros, O.K. , The ABCs of Desalting, 2nd ed., International Desalination Association, Topsfield, MA, 2000.

Cech, T.V. , Principles of Water Resources: History, Development, Management, and Policy, John Wiley & Sons, New York, 2003.

Committee on Advancing Desalination Technology , Desalination: A National Perspective, National Academies Press, Washington, DC, 2008.

CUWCC , Save Water, Money, Energy Now! Top 5 Actions, California Urban Water Conservation Council, 2006, http://www.h2ouse.org/action/top5.cfm.

Department of Community Affairs, Office of Environmental Management, State of Georgia , Every drop counts, Earth911.com , https://www.dca.ga.gov/sites/default/files/everydropcountsbrochure.pdf

Dolan, R. and Goodell, H.G. , Sinking cities, American Scientist, 74, 38–47, 1986.

Galloway, D.L. , Jones, D.R. , and Ingebritsen, S.E. , Land Subsidence in the United States, FS-165-00, U.S. Geological Survey, Denver, CO, 2000.
Gaughen, B. , Making every drop count: water conservation in Santa Barbara, Western City, September, 14–17, 1990.
Gleick, P.H. , Making every drop count, Scientific American, 284(2), 40–45, 2001.
Henthorne, L. , The Current State of Desalination, International Desalination Association, Topsfield, MA, 2011.
Kenny, J.F. , Barber, N.L. , Hutson, S.S. , Linsey, K.S. , Lovelace, J.K. , and Maupin, M.A. , Estimated Use of Water in the United States in 2005, Circular 1344, U.S. Geological Survey, Denver, CO, 2009, http://pubs.usgs.gov/circ/1344/.
Klenin, G. , California's Water–Energy Relationship, Final Staff Report, CEC-700-2005-011-SF, California Energy Commission, Sacramento, CA, 2005.
Kusky, T.M. , Geological Hazard: A Sourcebook, Greenwood Press, Westport, CT, 2003.
Larmer, B. , Bitter waters: can China save the Yellow – its Mother River?, National Geographic Magazine, May, 146–169, 2008, http://ngm.nationalgeographic.com/2008/05/china/yellow-river/larmer-text. https://www.monobasinresearch.org/timelines/publictrust.php
Leake, S.A. , Land Subsidence from Ground-Water Pumping, U.S. Geological Survey, Denver, CO, 2004, http://geochange.er.usgs.gov/sw/changes/anthropogenic/subside/.
Martindale, D. and Gleick, P.H. , How we can do it, Scientific American, 284(2), 38–41, 2001.
Milstein, M. , Water woes, National Parks, May–June, 39–45, 1992.
Mono Lake Committee , The Public Trust Doctrine at Mono Lake, Mono Basin Clearinghouse, January 10, 2007,https://www.monobasinresearch.org/timelines/publictrust.php
Polak, P. , The big potential of small farms, Scientific American, 293(3), 84–91, 2005.
Postel, S. , Growing more food with less water, Scientific American, 284(2), 46–51, 2001.
Reisner, M. , Cadillac Desert: The American West and Its Disappearing Water, Penguin Books, New York, 1993.
Rogers, P. , Facing the freshwater crisis, Scientific American, 299(2), 46–53, 2008.
Rudolph, M. , Urban hazards: sinking of a titanic city, Geotimes, July, 2001 http://www.geotimes.org/july01/sinking_titanic_city.html
Sachs, J.D. , The challenge of sustainable water, Scientific American, 295(6), 48, 2006.
Shiklomanov, I.A. , Evolution of Global Water Use: Withdrawal and Consumption by Sector, State Hydrological Institute, St. Petersburg, and United Nations Educational Scientific and Cultural Organisation, UNESCO, Paris, 1999.
Solley, W.B. , Pierce, R.R. , and Perlman, H.A. , Estimated Use of Water in the United States in 1995, USGS Circular 1200, U.S. Geological Survey, Denver, CO, 1998.
Sterea, A. , Foreign policy in focus, The Looming U.S. Water Crisis, December 19, 2019. https://www.commondreams.org/views/2019/12/19/looming-us-water-crisis
Turk, J. and Turk, T. , Environmental Science, 4th ed., Saunders, New York, 1988, p. 494.
Tyler Miller, Jr., G. , Living in the Environment: An Introduction to Environmental Science, 6th ed., Wadsworth, Belmont, CA, 1990, p. 250.
UNEP , Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters, 2002 ; https://www.unep.org/resources/report/vital-water-graphics-overview-state-worlds-fresh-and-marine-waters
USEPA , Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs, EPA 832-B-02-003, U.S. Environmental Protection Agency, Washington, DC, 2002.
USGS , Total Water Use in the United States, United States Geological Survey, Reston, VA, 2018, https://www.usgs.gov/media/images/trends-total-water-withdrawals-water-use-category-1950-2015-0.
Ward, D.R. , Water Wars: Drought, Flood, Folly, and the Politics of Thirst, Riverhead Books, New York, 2002.
WWAP , UN Water Development Report (WWDR4), Vol. 1, Managing Water under Uncertainty and Risk, United Nations World Water Assessment Programme, Paris, 2012.

Water Quality

Anon. , Preventing more BP-type oil disasters, Earthjuctice.org , 2013, http://earthjustice.org/features/preventing-more-bp-type-oil-disasters.

Antonie, R.V. , Fixed Biological Surfaces – Wastewater Treatment, CRC Press, Boca Raton, FL, 1976, p. 10.

Biever, M. , Yuma desalting plant pilot run final report, Reclamation, Managing Water in the West, 2012. https://www.usbr.gov/lc/yuma/facilities/ydp/YDPPilotRunFinal072712.pdf.

Chowdhury, A.M. , Arsenic crisis in Bangladesh, Scientific American, 291(2), 87–91, 2004.

Collie, M. and Russo, J. , Deep-Sea Biodiversity and the Impacts of Ocean Dumping, NOAA Research, National Oceanic and Atmospheric Administration, Silver Spring, MD, 2001.https://oceanexplorer.noaa.gov/explorations/deepeast01/background/dumping/dumping.html.

Curtius, M. , A sewage plant tourists love, SFGate.com , December 18, 1998, http://www.sfgate.com/news/article/A-Sewage-Plant-Tourists-Love-Arcata-s-low-tech-2973312.php.

Davis, T. , Test run on Yuma desalination plant a success, Arizona Daily Star, June 28, 2012, http://azstarnet.com/news/science/health-med-fit/test-run-on-yuma-desalination-plant-a-success/article_9b5ecc07-96da-57f5-a1b7-d2dd94726a00.html.

Doyle, R. , Darkness on the water, Scientific American, 296(4), 26, 2007.

Embach, C. , Oil spills: impact on the ocean, WaterEncyclopedia.com , 2013, http://www.waterencyclopedia.com/Oc-Po/Oil-Spills-Impact-on-the-Ocean.html.

IBWC , Colorado River Boundary Section, International Boundary & Water Commission, El Paso, TX, http://www.ibwc.gov/Water_Data/Colorado/Index.html.

JMP , Joint Monitoring Programme (JMP) for Water Supply and Sanitation, WHO-UNICEF, Geneva, 2013, http://www.wssinfo.org.

Mallin, M.A. , Wading in waste, Scientific American, 294(6), 53–59, 2006.

Mason, W.R. , Pollution of groundwater, WaterEncyclopedia.com , 2013, http://www.waterencyclopedia.com/Oc-Po/Pollution-of-Groundwater.html.

NOAA , 1998 Year of the Ocean: A Survey of International Agreements, National Oceanic and Atmospheric Administration, Silver Spring, MD, 2013, https://www.ospo.noaa.gov/Organization/About/international.html.

NOAA , Gulf Oil Spill, NOAA Education Resources, National Oceanic and Atmospheric Administration, Silver Spring, MD, 2011, http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html.

Querna, E. , A plan for water, Scientific American, 291(2), 25–26, 2004.

Sandler, G. , Yuma plant meant to conserve water will cost millions to update, 2018, https://cronkitenews.azpbs.org/2018/05/02/yuma-plant-meant-to-conserve-water-will-cost-millions-to-update/.

Senior, J. , Yannawa wastewater project, Bangkok, Thailand, ARUP Journal, 3, 35–41, 2000.

USDA , U.S. Fertilizer Use and Price, Economic Research Service, U.S. Department of Agriculture, Washington, DC, 2012, http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx.

USEPA , Ocean Dumping and Dredged Material Management, EPA-842-F-05-001d, U.S. Environmental Protection Agency, Washington, DC, 2005.

USEPA , 2000–2001 Pesticide Market Estimates: Usage, U.S. Environmental Protection Agency, Washington, DC, 2006, http://www.epa.gov/pesticides/pestsales/01pestsales/usage2001.htm.

USEPA , Frequent Questions about Underground Storage Tanks, U.S. Environmental Protection Agency, Washington, DC, 2020. https://www.epa.gov/ust/frequent-questions-about-underground-storage-tanks.

Vesilind, P.A. and Peirce, J.J. , Environmental Pollution and Control, 2nd ed., Butterworth, Boston, MA, 1983, pp. 87, 95.

Wellton–Mohawk , Challenges, Wellton–Mohawk Irrigation and Drainage District, Wellton, AZ, 2004, http://www.wellton-mohawk.org/challenges.html.

Solid Wastes

Aluminum: Material-Specific Data Facts and Figures about Materials, Waste and Recycling. US EPA, October 7, 2020, https://www.epa.gov.

Anon. , Manila squatters buried by garbage; more than 50 killed when giant trash heap collapses and crushes shantytown, The Washington Post, July 11, 2000, p. A16.

Arms, K. , Environmental Science, Saunders, New York, 1990.

ASU , Where Does It Go From Here? Recycling at ASU, Arizona State University, Phoenix, AZ, http://property.asu.edu/recycle/how.html.

Celdran, A.M. and Sahakian, M. , Smokey Mountain Remediation & Development Program (SMRDP), Asian Development Bank, Manila, 2007, https://www.povertyenvironment.net/files/37715-REG-TACR.pdf.

Cunningham, W.P. and Saigo, B.W. , Environmental Science: A Global Concern, Wm. C. Brown, Dubuque, IA, 1990.

France-Presse, A. , Danger lurks under Smokey Mountain, The Manila Times, August 2, 2006. https://www.manilatimes.net/2006/08/02/news/top-stories/danger-lurks-under-smokey-mountain/777564/.

Hill, J.W. , Chemistry for Changing Times, 6th ed., Macmillan, New York, 1992, p. 334.

Joesten, M.D. , Netterville, J.T. , and Wood, J.L. , World of Chemistry: Essentials, Saunders, New York, 1993, p. 209.

Kreith, F. and Tchobanoglous, G. , Handbook of Solid Waste Management, McGraw-Hill, New York, 2002.

Lee, G. , The aluminum can: America’s most successful recycling story that you’ve never heard, GreenBiz, November 15, 2019, https://www.greenbiz.com/article/aluminum-can-americas-most-successful-recycling-story-youve-never-heard.

Lindstrom, P. , Methane emissions, in Emissions of Greenhouse Gases in the United States 2003, Energy Information Administration, U.S. Department of Energy, Washington, DC, 2004, ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/ggrpt/057303.pdf.

Melosi, M.V. , Garbage in the Cities: Refuse, Reform, and the Environment, University of Pittsburgh Press, Pittsburgh, PA, 2005.

National Overview: Facts and Figures on Materials, Wastes and Recycling, November 10, 2020, https://www.epa.gov.

Nshimirimana, J. , Attitudes and Behaviour of Low-Income Households towards the Management of Domestic Solid Waste in Tafelsig, Mitchell’s Plain, PhD thesis, University of the Western Cape, Capetown, South Africa, 2004.

Tchobanoglous, G. and Kreith, F. , Eds., Handbook of Solid Waste Management, 2nd ed., McGraw-Hill, New York, 2002.

Leblanc, R. , The amazing story of lead recycling, The Balance Small Business, October 7, 2018,https://www.thebalancesmb.com/the-amazing-story-of-lead-recycling-2877926.

USEPA , 2003 data tables, in Municipal Solid Waste in the United States: Facts and Figures, U.S. Environmental Protection Agency, Washington, DC, 2003, Table 7, http://www.epa.gov/epawaste/nonhaz/municipal/msw99.htm.

USEPA , Municipal Solid Waste, U.S. Environmental Protection Agency, Washington, DC, 2020, http://www.epa.gov/epawaste/nonhaz/municipal/index.htm.

World Bank , Urban Poverty and Slum Upgrading: Environment: Poverty and Urban Environmental Conditions, The World Bank, Washington, DC, 2011, http://web.world-bank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTURBANPOVERTY/0,contentMDK:20234025~menuPK:7173807~pagePK:148956~piPK:216618~theSitePK:341325~isCURL:Y,00.html.

Hazardous Wastes

Anon. , GAO warns about Hanford cleanup, Chemical & Engineering News, 84(37), 25, 2006.

Anon. , DOE resubmits nuclear waste bill, Chemical & Engineering News, 85(11), 28, 2007.

Anon. , DOE to assess new radioactivity class, Chemical & Engineering News, 85(31), 44, 2007.

Anon. , Timeline – The Nuclear Waste Policy Dilemma, YuccaMountain.org, Nuclear Waste Office, Eureka County, Nevada, 2013, http://www.yuccamountain.org/time.htm.

Applegate, J.S. and Laitos, J. , Environmental Law: RCRA, CERCLA, and the Management of Hazardous Waste, Foundation Press, New York, 2006.

ATSDR , Tar Creek Superfund Site – Ottawa County, OK, Agency for Toxic Substances & Disease Registry, U.S. Department of Health and Human Services, Washington, DC, 2010, http://www.atsdr.cdc.gov/sites/tarcreek/.

Baker, R. and Simpson, F.S. , State of California Reaches Historic Settlement for Stringfellow Hazardous Waste Site [news release], Department of Toxic Substances Control, California Environmental Protection Agency, Sacramento, CA, 1999.

Cann, M.C. and Connelly, M.E. , Real World Cases in Green Chemistry, American Chemical Society, Washington, DC, 2000.

Cooney, C.M. , Illuminating the future for bioremediation, Environmental Science & Technology, 34(7), 162A, 2000.

Cunningham, W.P. and Saigo, B.W. , Environmental Science: A Global Concern, Wm. C. Brown, Dubuque, IA, 1990, p. 488.

DePalma, A. , Love Canal declared clean, ending toxic horror, The New York Times, March 18, 2004, p. A1.

Eilperin, J. , Lack of money slows cleanup of hundreds of Superfund sites; federal toxic waste program’s budget is stagnant, The Washington Post, November 25, 2004, p. A1.

Engelhaupt, E. , Happy birthday, Love Canal, Environmental Science & Technology, 42(22), 8179–8186, 2008.

FEA , Background Paper on Permanent Storage in Salt Mines, Federal Environment Agency, Berlin, 2004, http://www.basel.int/techmatters/popguid_may2004_ge_an1.pdf.

GAO , Hazardous Waste Sites: State Cleanup Status and Its Implications for Federal Policy, GAO/RCED-89-164, U.S. General Accounting Office, Washington, DC, 1989.

Hogue, C. , Toxics inventory, Chemical & Engineering News, 83(20), 9, 2005.

Hogue, C. , EPA to remove dioxin-contaminated Hooker Chemical landfill from list of nation’s most hazardous waste sites, Chemical & Engineering News, 90(35), 26, 2012.

Joesten, M.D. , Netterville, J.T. , and Wood, J.L. , The World of Chemistry: Essentials, Saunders, New York, 1991, p. 261.

Johnson, J. , Reprocessing key to nuclear plan, Chemical & Engineering News, 85(25), 48–54, 2007.

Kemsley, J. , Bacterium snacks on vinyl chloride, Chemical & Engineering News, 81(27), 8, 2003.

Melfort, W.S. , Nuclear Waste Disposal: Current Issues and Proposals, Nova Science, New York, 2003.

OEM , Early environmental management history (1989–1992) timeline, U.S. Department of Energy, Washington, DC, 2021. https://www.energy.gov/em/early-environmental-management-history-1989-1992-timeline.

Pichtel, J. , Waste Management Practices: Municipal, Hazardous, and Industrial, Taylor & Francis, Boca Raton, FL, 2005.

Purin, G. , Orttung, J. , Van Stockum, S. , and Page, J. , Alternatives to Landfilling Household Toxics, Golden Empire Health Planning Center, Sacramento, CA, 1987, pp. A176–A178.

Richardson, R. , Home Hints and Tips: The New Guide to Natural, Safe and Healthy Living, DK Publishing, New York, 2003.

Ritter, S.K. , Green chemistry, Chemical & Engineering News, 79(29), 27–34, 2001.

Tuchman, G. , Despite toxic history, residents return to Love Canal, CNN.com, August 7, 1998, http://www.cnn.com/US/9808/07/love.canal/.
USDOE , Why WIPP?, WIPP Information Center, U.S. Department of Energy, Washington, DC, 2007, http://www.wipp.energy.gov/fctshts/Why_WIPP.pdf.
USEPA , Love Canal, New York, EPA Region 2 Report, NYD000606947, U.S. Environmental Protection Agency, Washington, DC, 2007.
USEPA , Superfund: Basic Information, U.S. Environmental Protection Agency, Washington, DC, 2012, http://www.epa.gov/superfund/about.htm.

Epilogue

Thunberg, Greta , No One Is Too Small to Make a Difference, Penguin, London, 2019.
Thunberg, Greta , et al., *Our House Is on Fire: Scenes of a Family and a Planet in Crisis*, Penguin, London, 2018.