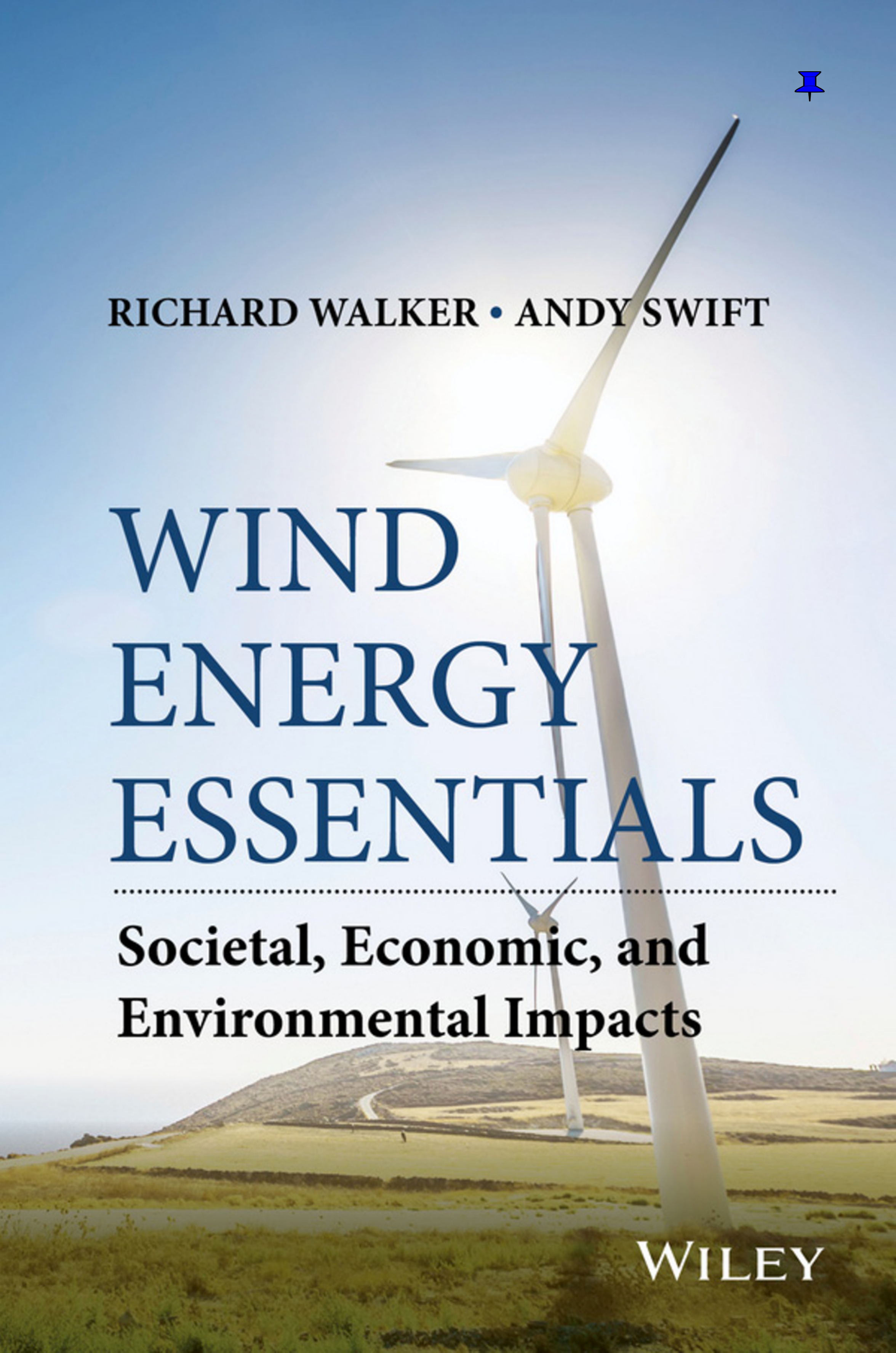

RICHARD WALKER • ANDY SWIFT

WIND ENERGY ESSENTIALS

Societal, Economic, and Environmental Impacts

WILEY

WIND ENERGY ESSENTIALS

WIND ENERGY ESSENTIALS

Societal, Economic, and Environmental Impacts

RICHARD P. WALKER
ANDREW SWIFT

WILEY

Published by John Wiley & Sons, Inc., Hoboken, New Jersey
Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data:

Walker, Richard P., 1957–
Wind energy essentials : societal, economic, and environmental impacts / Richard P. Walker, Andrew Swift.
pages cm
Includes bibliographical references and index.
ISBN 978-1-118-87789-0 (cloth : alk. paper) 1. Wind power plants. 2. Wind energy. I. Swift, A. H. P. (Andrew H. P.) II. Title.
TK1541.W346 2015
333.9′2–dc23

2015007886

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

CONTENTS

PREFACE

As a nation, the United States uses a lot of energy and in most years, energy use increases. While the efficiency with which the United States uses energy has increased over time, this improvement has not been able to offset overall growth in energy use. Electricity generation accounts for about 40% of the nation's energy use, with the vast majority of this being produced using either fossil fuels or nuclear energy. Renewable resources are used to meet less than 15% of US electricity needs as of the writing of this book, with hydroelectric generation accounting for most of that.

While installed wind generating capacity has grown rapidly in the United States over the last several years, its primary competition in the electricity market, natural gas–fired generation, has benefited from new extraction technologies such as horizontal drilling and fracking, resulting in low natural gas prices, as well as power plant efficiency improvements. Wind energy's growth has been spurred on by the Federal production tax credit (PTC), which has helped make wind very cost-competitive with natural gas generation. However, Congress has allowed the PTC to lapse several times since it was first enacted in 1992, causing severe disruptions in the US wind energy industry. On the other hand, public opposition and increasingly stringent environmental regulations make it very difficult to construct new coal-fired or nuclear power plants in the United States. Thus, most new electric generating capacity in the country has come from natural gas–fired power plants or wind power plants in recent years, although advances in solar energy technology resulting in higher efficiency and lower cost indicate that it will become a major contributor to the nation's power supply in coming years.

Globally, wind power's growth has been more stable than in the United States, with an average annual growth rate of over 25% since 1998. The demand for electricity in highly populated developing nations such as China, India, Indonesia, Brazil, and Pakistan will place increasing demand on fossil fuels, further compounding environmental issues such as smog and global climate change. However, many of these nations are also looking to renewable energy as a means to meet their rapidly growing demand for electricity with their own domestic resources.

Wind energy will continue to grow rapidly, and although it is one of the cleanest and most environmentally neutral energy sources, wind projects can negatively affect wildlife habitat and individual species unless careful and thoughtful consideration is given to the potential impacts of these wind projects. This book is intended to familiarize the reader with wind technology, the economics of electricity generation, and energy policy. In addition, our hope is that it also helps to enable the wind energy industry to conduct itself in a socially responsible manner consistent with high standards for environmental stewardship, while helping to preserve the Earth's natural resources, including air quality, water, wildlife, and scenic areas.

Dr. Richard P. Walker
Dr. Andrew Swift

FOREWORD

This comprehensive work by Richard Walker and Andrew Swift occupies a unique position in the literature about wind energy. There are many books on wind energy—most, however, are technical in nature and serve as guides for designers. To my knowledge, there are none that span the broad range of environmental, financial, policy, and other topics that define and determine the relationships between wind energy technology and our energy-dependent society. As a consequence of their teaching and industrial experience, both authors are comfortable with the technology of wind energy and other renewables. In addition, the Texas Tech educational program in wind energy always has moved beyond technology to include the topics covered in this book. While the focus is on wind energy, much of the material in this book is applicable to other renewables as well. In that sense, this contribution bridges the technology of renewables with their societal impacts.

As may be seen from the Table of Contents, the authors have included just enough technology description to serve as a foundation for their discussions of environmental and societal issues. The technology descriptions should enable the reader to have a deeper insight and appreciation of the interdependencies between the capabilities of the technology and the impacts that go beyond the provision of electricity. For example, it is well known that the energy and economic productivity of the technology has improved by orders of magnitude since the early 1980's onset of significant installations in Europe and the United States. What is not as well known is that wind energy technology also has evolved significantly in response to societal concerns. These concerns have included impacts on wildlife, land use and permitting, safety and potential public health concerns, and interactions with the electrical grid. The authors deal with these as well as with many other relevant concerns.

The full title of the book gives a preview of the breadth of the subject. In particular, the subtitle *Societal, Economic, and Environmental Impacts* provides a first hint of the breadth of the treatment provided in this book by Walker and Swift. For those who wish to have a grounding in the technology and an objective, comprehensive treatment of the societal impacts, this book will provide the needed background and insight. It is a unique resource.

Time-Variable Systems, LLC
May 26, 2014

DR. JAMIE CHAPMAN

ABOUT THE AUTHORS

Richard P. Walker, PhD, PE

Dr. Richard Walker first joined the wind energy industry in 1994 and since that time has been a pioneer of wind development efforts in Texas beginning with the development of the first utility-scale wind project in Texas. His career has spanned over 30 years including working in the electric utility industry, wind project development, consulting, and teaching at Texas Tech University. He has been involved in the development of over 1600 MW of wind farms currently in operation, including the first wind development in Sweetwater, Texas area (the Trent Wind Farm), and the Roscoe Wind Farm, which was the world's largest wind energy project at 782 MW for several years. Dr. Walker is the President of Sustainable Energy Strategies, Inc., which provides consulting services to utilities, developers of renewable energy projects, and large landowners, and he is the President of RD Energy Group, LLC, an early-stage developer of renewable energy projects. He is a registered professional engineer in the state of Texas and holds BS (Civil Engineering) and MBA (Finance) degrees from Texas A&M University and a PhD in Wind Science and Engineering from Texas Tech University. While at Texas Tech, he developed and taught several of the university's courses in wind energy. In 2003, Dr. Walker was awarded the American Wind Energy Association's award for outstanding contribution to the wind industry. He has served on the board of directors for several organizations including the American Wind Energy Association, the Texas Renewable Energy Industries Association, the Utility Wind Interest Group, the Solar Electric Power Association, and the Central Electric Vehicle Consortium. Dr. Walker and his wife, Connie, have been married for 30 years and have three children.

Andrew Swift, ScD, PE

Dr. Andrew Swift is presently Professor of Civil and Environmental Engineering and Associate Director of the National Wind Institute at Texas Tech University—focused on Wind Energy Education and Workforce Development. His previous academic appointments include Director of the Texas Wind Energy Institute and the Wind Science and Engineering Research Center at Texas Tech and Dean of the College of Engineering at the University of Texas at El Paso. He completed his engineering graduate work obtaining a Doctor of Science degree at Washington University in St. Louis where he began conducting research in wind turbine systems engineering with a focus on the dynamics and aerodynamics of wind turbine rotors. Dr. Swift has worked in wind energy research and education for over 30 years; has over 100 published articles and book chapters in the area of wind turbine engineering and renewable energy; and in 1995 received the American Wind Energy Association's Academic Award for continuing contributions to wind energy technology as a teacher, a researcher, and an author. He is a native of Upstate New York, and his background includes military service as an Air Force pilot and flight instructor. His wife, Linda is a native of West Texas, and they have two daughters and three grandchildren.

DEDICATION AND ACKNOWLEDGMENTS

This book is dedicated to our wives, Linda Swift and Connie Walker, for their support over many years working in the uncertain field of renewable energy and tolerating the countless hours that we worked on this book, and also to our children and their spouses—Luke and Sarah Walker, Amy and Ben Marcotte, Molly Walker, Carolyn and Kevin Kuhnel, and Karen and Jeff Eagleston.

We also wish to acknowledge the contributions of Amy Marcotte, Kyle Jay, Chance Howe, Charles and Dorothy Norland, and Elizabeth Paulk for their help with proofreading, graphics design, photography, and research.

1

IMPACTS OF ENERGY AND ELECTRICITY ON SOCIETY

1.1 WHAT ARE "SOCIAL AND ENVIRONMENTAL IMPACTS"?

1.1.1 Interactions and Effects of Technology on Society and the Environment

We begin with two fundamental characteristics of human nature. First, humans develop and use technology, beginning with stone tools, the use of fire and heat, the plow, and agriculture—to modern times where we have developed electric utilities, computers, and cell phones. Second, humans are social beings and live in groups. Since the earliest times, these two elements of human development have been major contributors to modern civilized society. Technological developments used to the benefit of society usually provide a general improvement in the quality of life (QOL), to include security (such as defense against other people or animals; warfare activities; or natural phenomena such as earthquakes, floods, and windstorms). Other developments, such as politics, economics, philosophy, and education have also been key elements in this development, but our focus in this text is on the interactions of technology, society, and the environment with a particular emphasis on the impacts of wind energy development.

In addition to societal impacts, technology development often impacts the natural environment. The process of generating energy has very significant impacts on the natural environment. This began from the earliest cave dwellers harvesting wood to burn for warmth and light through today where modern society depends on fossil fuels to provide the majority of our energy needs. As will be discussed, the

Wind Energy Essentials: Societal, Economic, and Environmental Impacts, First Edition.
Richard P. Walker and Andrew Swift.

environmental impact of the production, distribution, and use of energy has significant impact on the natural environment, especially as the need for energy has grown with an expanding population.

1.1.2 Sustainable Development

Over the last several decades, the impact of rapid technological progress on the global environment, as well as growing populations, has heightened concerns about negative environmental effects and the growing demand for limited natural resources. These concerns have led to the concept of "sustainable development." The word "sustainability" is derived from the Latin word *sustinere* (*tenere*, to hold; *sus*, up). Dictionaries provide more than 10 meanings for *sustain*, the main ones being to "maintain," "support," or "endure." However, since the 1980s *sustainability* has been used more in the sense of human sustainability on Earth and this has resulted in the most widely quoted definition of sustainability and sustainable development—that of the Brundtland Commission of the United Nations on March 20, 1987:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. [1]

In other words, sustainable development minimizes the impact of resource use so that the needs of the present generation are met without diminishing the ability of future generations to meet their needs.

1.1.3 Wind Power, Technology, and Society

Our study will focus on one of the most basic elements of our planetary environment: the wind. This chapter will examine wind technologies developed over many centuries to harness the power of the wind for an improved QOL and how it has impacted society, both in centuries past and today. We will begin with a historical overview of wind power technological accomplishments, such as the age of discovery using sailing ships, the importance of wind power in providing transportation across the developing United States and settling the central Great Plains, to early electricity production using wind power. This will be followed by an overview of wind science and technology with an in-depth focus on modern global utility-scale wind power development for electrical power production.

1.2 EARLY WIND POWER INNOVATION AND DISCOVERY

1.2.1 Age of Sail Power

Using wind to power sailing vessels has had major impacts on society throughout the history of civilization. Sailing vessels have allowed humans greater mobility for thousands of years and have increased the capacity for fishing, trade, commerce, transport, naval defense, and warfare. The earliest image of a ship under sail was painted on a disk found in the Middle East dating to the fifth millennium BC. In the sixth century, development of the Lateen Rig in Arabia, shown in Figure 1.1, allowed vessels to travel in an upwind direction. Sails used previously could only develop a motive force moving with the wind direction (downwind) and required oarsmen to travel in an upwind direction. This was a major innovation since the vessel could now travel in all directions solely with the power of the wind.

Sailing ships became considerably larger over the centuries, as well as more seaworthy, with improved techniques for harnessing the wind. These advances along with improved navigational techniques allowed sailors to travel the seas worldwide. Sailors learned to use global wind patterns to reduce the time of long trips connecting distant societies in ways that were previously not possible.

One of the periods of most significant change and impact occurred during what is often referred to as the "Age of Discovery" from the fifteenth through the seventeenth century. During this time, such familiar names as Columbus and Magellan set out on famous and historical sailing journeys. Columbus discovered the "New World," while Magellan was the first to lead an expedition that circumnavigated the globe. Leaving Portugal in 1519 with five ships, his fleet returned to Spain in 1522 led by Juan Sebastian, due to the death of Magellan in the Philippines during the 3-year voyage.

The golden age of sail, however, is usually considered to be during the nineteenth century, when sailing vessels had become quite large and the efficiency of long-distance sailing was at its peak. Trade during the golden age was dominated by huge numbers of sailing vessels, following routes defined by the "Trade Winds" and navigating to all parts of the globe providing trade, commerce, and immigration of large numbers of people—changing societies and cultures around the world. This was also a time when the most powerful nations on Earth had large naval fleets of sailing vessels, not only for their own sovereign protection but also to protect shipping lanes and spread power and influence throughout the world. The British Empire, for example, depended heavily on its strong navy of sailing warships to build, to expand, and to protect its empire during this period in the nineteenth century. Figure 1.2 shows the USS Constitution. Named in 1797 by President George Washington, it was one of the ships commissioned for the newly formed U.S. Navy. The ship is best known for her actions in the War of 1812 where she earned the name "Old Ironsides."

In addition to trade, immigration, and national defense, nineteenth century commercial sailing vessels harvested the seas for food and commodities—the most well-known being the whaling fleet. Whaling ships, like the Charles W. Morgan shown in Figure 1.3, would embark on multiyear journeys to hunt whales. In the nineteenth century, whales were abundant and were harvested for the high-quality oil they contained, as it was a valued commodity due to the clean-burning light provided by a whale oil lamp.

Without electricity, candles and lamps provided the only light. Whaling ships could hold in the order of 2000 barrels of oil, valued between $200 and $1500 per barrel (2003 US dollars). Voyages would last until the ship's hold was full, sometimes up to 5 years. Driven by the high value of the whale oil and ever-improving

(a)

(b)

FIGURE 1.1 A Dhow sailing vessel with Lateen rigged sails (a) and one of the most popular recreational sailboats, the Sunfish (b), which use the same ancient sail design. This was the first sail design that allowed sailboats to tack (go back and forth at an angle) allowing travel upwind. Modern wind turbines are driven by similar crosswind (lift) forces. See more about lift forces in Figure 4.5 (Photo Credit—upper photo: Xavier Romero-Frias, http://en.wikipedia.org/wiki/File:Sd2-baggala.JPG; lower photo: Dierde Santos, http://en.wikipedia.org/wiki/File:SunfishRacing.jpg).

FIGURE 1.2 The restored USS Constitution under sail, a warship of the first U.S. Navy (Source: Photo Courtesy of U.S. Navy).

FIGURE 1.3 Charles W. Morgan Whaling Ship, Mystic Seaport, CT (Photo Credit: Mystic Seaport, http://en.wikipedia.org/wiki/File:Charles_W_Morgan.jpg).

sailing vessels, the industry flourished in the nineteenth century, driving the whale population to near extinction. The discovery of petroleum products, in particular kerosene, led to the replacement of whale oil and the decline of the industry. None of these aspects of world history would have been possible without the use of wind-driven ships.

1.2.2 Wind Power and the Transcontinental Railroad

Late in the eighteenth century, the steam locomotive was invented nearly simultaneously in England and in the United States. England, however, was the location of the development of the first railway system, built at the turn of the nineteenth century. The locomotives used steam produced with a water boiler and firebox, usually fueled with wood or coal, to provide the heat needed to create steam used to drive the large steam-pistons that powered the locomotive. For more than 150 years, the railroad dominated freight and passenger land transportation, as sail power dominated sea transportation. Prior to the nineteenth century, most development in the United States was east of the Mississippi river and along the West Coast. Both of these areas had plentiful quantities of wood, coal, and water to provide the fuel and steam to power large-scale railroad networks with steam locomotives.

By 1850, a network of rail lines had connected most parts of the eastern half of the United States and coastal areas along the West Coast, but there was no effective way to connect the coasts and to cross what was then called the "Great American Desert," now known as the Great Plains. The wagon trains of the early 1800s and Pony Express riders carrying the mail were not the solution a growing nation needed. In order to unify the nation, it was important to connect the eastern and western portions of the United States with a means of bulk transportation that was efficient in both time and cost and could move people and goods effectively and rapidly.

Throughout the decades of the 1840s and 1850s, there was significant interest to build a rail line to connect the east and west portions of the nation. The task was substantial and of a magnitude that required government support. Construction was finally authorized by the Pacific Railroad Act of 1862 and 1864—at the same time the American Civil War was being waged. It was funded with 30-year US bonds and extensive grants of government-owned land to the railroad companies to build the line (Fig. 1.4).

The final link of the "Transcontinental Railroad," as it was called, was a route from the twin cities of Council Bluffs, Iowa, and Omaha, Nebraska, in the central part of the United States—via Ogden, Utah, and Sacramento, California, ending at the Pacific Ocean in Oakland, California. The coast-to-coast rail line was popularly known as the Overland Route and continued passenger rail service until 1962—almost 100 years. The Overland Route's final link was built by the Central Pacific Railroad of California from the west and the Union Pacific Railroad from the east between the years of 1863 and 1869 when the last spike was driven at Promontory Summit, Utah on May 10, 1869. That final spike completed the Overland Route, establishing a rail link for transcontinental transportation that not

FIGURE 1.4 Photograph of the driving of the Golden Spike, Promontory, Utah, 1867 (Photo Credit: Andrew J. Russell, http://en.wikipedia.org/wiki/File:1869-Golden_Spike.jpg).

only united the country from coast to coast but also opened the heartland for settlement and development. The Transcontinental Railroad is considered one of the greatest accomplishments of the nineteenth century, surpassing the building of the Erie Canal in the 1820s and crossing the Isthmus of Panama by the Panama Railroad in 1855.

But what is the connection between wind power and the transcontinental railroad? In the continental United States, areas west of the Mississippi river receive much less rain than areas east of the Mississippi river. As mentioned earlier, in nineteenth century America, many people referred to the area as the “Great American Desert” due to the lack of rain and surface water, and since it was mostly grassland and prairie. Steam locomotives, however, required water to operate—large quantities of water. In fact, steam engines at the time required 100–200 gallons of water for each mile that they travelled. As a result, crossing the arid region of the Great Plains was a significant challenge to railroad planners as they looked for large sources of boiler feed water for the steam locomotives. Wind power offered the solution.

Driven by the geography of the Rocky Mountains to the west and large flat expanses across the plains to the Mississippi River, the Great Plains are well known for their almost constant winds that blow across the region. Water-pumping windmills would use the winds of the Great Plains to drive pumps and to lift abundant

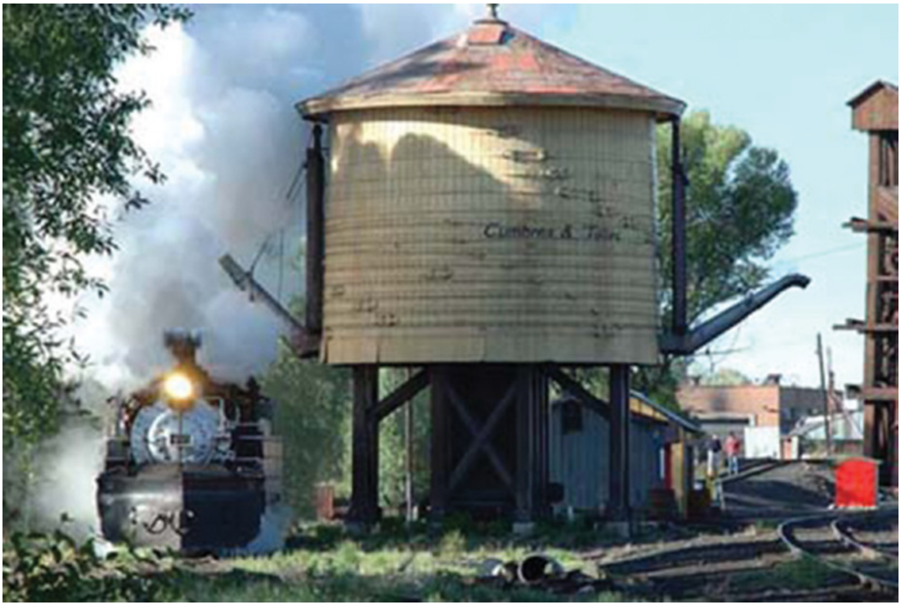

FIGURE 1.5 Railroad depot water tower (Photo Credit: Wdiehl, http://en.wikipedia.org/wiki/File:487_at_water.jpg).

underground water to storage tanks providing the needed water for the steam locomotives (Fig. 1.5). Companies such as Eclipse developed large, wooden, multibladed wind pumpers and installed them along the rail lines (Fig. 1.6).

Thus, as the Transcontinental Railroad developed, a wind-powered water-pumping industry developed in the country as well—to meet the needs and large water appetites of the steam engine. It would later turn out that this same industry would play a key role in settlement of the central United States.

Throughout the development of the American west, the lack of water was a major problem for not only the Transcontinental Railroad but the rail feeder-lines developed to support transportation to larger towns throughout the region. Locomotives could only travel approximately 20 miles between water stops, leading to the development of large numbers of small towns along the rail lines. A number of words and phrases of the time survive within our language and society today. For example, the many small towns that were developed as water and fuel stops needed names, and of course nicknames. If the water stop had surface water available but no wind-pumping or gravity feed system, men with buckets would have to take surface water from streams and ponds by tying ropes to the buckets and hauling the water into tanks for the steam locomotives—usually about 2000 gallons for every 20-mile stop. This bucket and rope process was called "jerking." If a town required this method of moving water, it was called a "jerk-water" town. It was, of course, populated by people of the same name (Fig. 1.7).