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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

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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

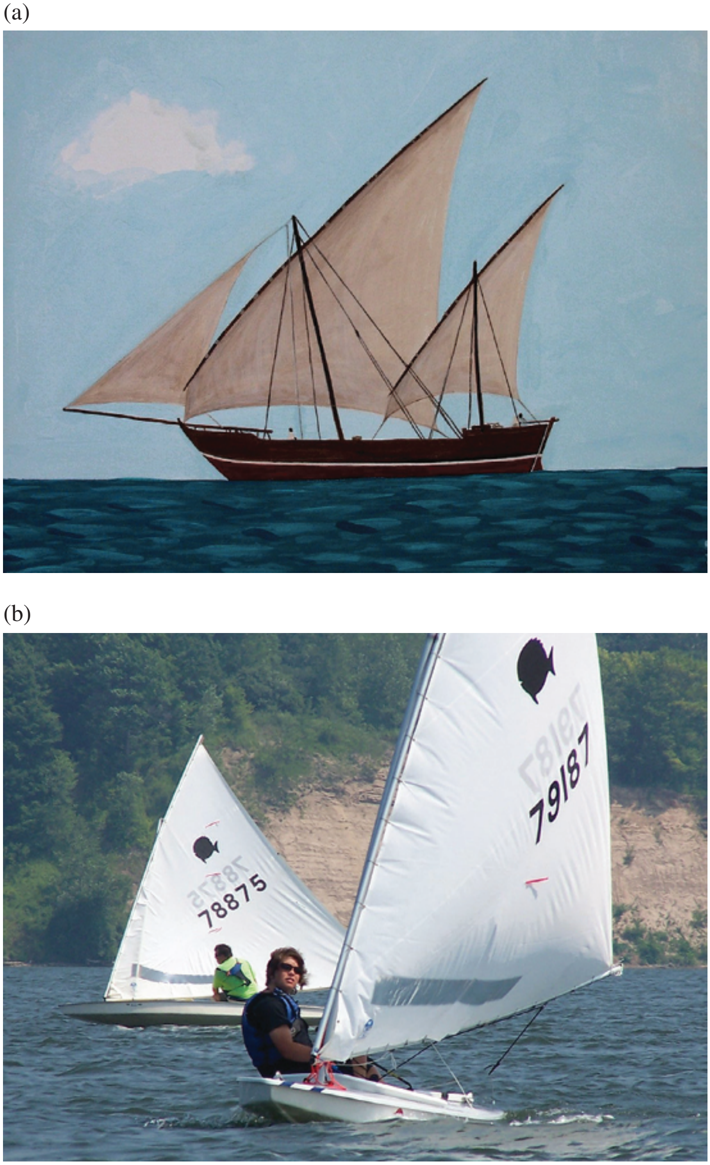

FIGURE 1.1 A Dhow sailing vessel with Lateen rigged sails (a) and one of the most popular recreational sailboats, the Sunfish (b), which use the same ancient sail design. This was the first sail design that allowed sailboats to tack (go back and forth at an angle) allowing travel upwind. Modern wind 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).

FIGURE 1.6 Eclipse wind pumper (Courtesy of I.G. Holmes, U.S. National Park Service).

FIGURE 1.7 1923 Burlington Route Steam Engine with fuel/water tender; National Ranching Heritage Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the National Ranching Heritage Center in Lubbock, TX).

1.2.3 Wind Power for Settling the Great Plains

Along with the Transcontinental Railroad connecting the eastern and western parts of the United States came settlement of the Great Plains with cities such as Denver, Colorado; Cheyenne, Wyoming; Albuquerque, New Mexico; and many more. Most of the region, however, was settled by farmers and ranchers who had water needs well in excess of that available with the minimal rains and sparse surface waters that existed throughout the Great Plains. Wind and wind-driven water pumpers, developed and adapted for farm and ranch use, allowed this settlement to occur at a scale that could not have been achieved otherwise (Figs. 1.8 and 1.9).

One of the most successful farm and ranch wind-driven water-pumping units was developed by Daniel Halladay in 1854. This wind-driven pumping unit had steel blades and used a steel tower that replaced older wooden construction and became a common sight throughout the mid-western United States providing water for both farms and livestock.

Before electrical pumps replaced wind-driven water pumpers in the 1930s, there were an estimated 600,000 units in operation with a total rated capacity equivalent to 150 MW of power. With installation numbers of this magnitude, a robust industry was required. The need for designers, engineers, manufacturers, part suppliers, installers, sales, marketing, and repair windsmiths provided a significant number of jobs and opportunities for this industry.

Halladay provided many features that improved the wind-driven water pump making it a reliable and effective way to pump underground water and to provide water services in areas where surface water was not available in sufficient quantities. The mid-western United States could not have been settled and developed without wind power before the electrification of the Great Plains (providing electric-driven pumping) in the 1940s.

Stationary steam power available at the time was just too cumbersome and expensive and, of course, required water in order to drive the units themselves. The impact of these wind-powered water pumps on regional development, not only in the United States but in many other parts of the world, can probably not be overstated (Figs. 1.9, 1.10, and 1.11).

1.2.4 The Dutch Experience

The country of the Netherlands, also called Holland, is so closely associated with the history of windmills that it is often the first fact that people recall when they think about this country on the western edge of the European continent. In addition to windmills, Holland is known for being a world power during the Dutch Golden Age and the commercial dominance of the Dutch West Indies Company as well as in tulips, commerce, trade, and art.

The Netherlands is a low-lying coastal country where 25% of the land is below sea level. The country is extremely prone to flooding due to its geography and in 1287, one of the most destructive floods in recorded history, the Saint Lucia's

FIGURE 1.8 Windmill used for water pumping to a nineteenth century ranch home. Texas Tech University, National Ranching Heritage Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the National Ranching Heritage Center in Lubbock, TX).

FIGURE 1.9 The American Water-Pumping Windmill and storage tank, key to settling the Great Plains of the United States in the nineteenth century. Texas Tech University, National Ranching Heritage Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the National Ranching Heritage Center in Lubbock, TX).

FIGURE 1.10 Windmill repair, nineteenth century; Photo reproduction from wall mural at the American Wind Power Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the American Wind Power Museum in Lubbock, TX).

flood, killed more than 50,000 people. In the thirteenth century, windmills were introduced on a large scale to pump water from low-lying areas, called polders—the name for an area of reclaimed land, usually enclosed by dikes, to form an artificial lowland suitable for agriculture and other uses. Without continual pumping and drainage, however, this land can flood, destroying any development on the reclaimed land (Fig. 1.12).

To maintain these lowland areas and to keep them productive, the Dutch continued to innovate and improve windmill drainage and pumping technology and by the year 1850, there were more than 50,000 windmills operating in the Netherlands. Many of these windmills were for the purpose of drainage and flood control, as described earlier, but they were also used for milling grains and for sawing wood. Even today, although the drainage pumps are mainly powered by electric motors and engine-driven pumps, windmills are often used for backup

FIGURE 1.11 Nineteenth century western town painting, Photo reproduction from wall mural at the American Wind Power Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the American Wind Power Museum in Lubbock, TX).

FIGURE 1.12 Wind Mills in the Netherlands (Photo Credit: Michiel1972, http://en.wikipedia.org/wiki/File:Zandwijkse_Molen.jpg).

power to maintain the required draining of the polders. Engineers have estimated that a typical Dutch windmill operating in a reasonable breeze produced 50 kW of power; thus, in the mid-nineteenth century, with 50,000 windmills operating, the Dutch had installed approximately 2,500 MW of mechanical windmill capacity to power their country—all at a time before the steam engine, the internal combustion engine, and the electric motor.

The Dutch Golden Age is typically considered to be during the seventeenth century, when Amsterdam was the wealthiest trading city and hosted a full-time stock exchange. The country had more than 16,000 merchant sailing ships to conduct trade and commerce worldwide bringing enormous wealth to the country. The Dutch West Indies Company had developed worldwide trading partners and during this time, the population of the country increased from 1.5 to 2 million people. Dutch wealth created an atmosphere in the country that supported famous artists, such as Johannes Vermeer, whose most famous painting called *The Girl with A Pearl Earring* is shown in Figure 1.13 in the "Mural of Dutch History." The painting inspired a modern book and movie of the same name. Without wind power to drive its commercial fleet of sailing ships, provide domestic power for mills, and for flood protection for the country, Holland would have not achieved the Dutch Golden Age.

The development of wind power and hydropower innovated over the centuries by the Dutch not only provided the energy base to drain the large polders but also provided the power and energy for ship building, grinding grain, and other uses to support its robust economy. The social impact of wind power on Dutch civilization and development during this period is remarkable. Even today, leadership in wind technology continues in the Netherlands. Delft University is a European leader in wind energy development. The group "DU Wind" at Delft is a wind energy research and technology organization focused on research, development, and education. The country has also hosted the installation of modern wind turbines with a rated capacity of several thousand megawatts.

FIGURE 1.13 Mural of Dutch History—Trade, Commerce, Tulips, Windmills, and Johannes Vermeer's *The Girl with a Pearl Earring* (Photo Credit: Anne97432, http://en.wikipedia.org/wiki/File:Hollande04.jpg)

1.2.5 The English Experience

The large-scale advent of windmills in England predated the expansion in the Netherlands by several centuries. The food economy of twelfth century England, like many societies throughout Europe and the world, depended heavily on grains. These were typically cereal grains such as wheat, barley, and oats. About half the food expenses of the typical household was for grain products to make bread, oat porridge, and so forth. For locations where waterpower was available to drive gristmills, flour from the grains could be produced mechanically. However, for other areas where water was scarce or not available, hand milling had to be done. Hand milling using a quern, or handheld grinding stone, took approximately two hours per day for a person to produce the flour needed for a household for a day. In the year 1080, a survey of water mills in England was conducted and indicated there were 5624 water mills operating, grinding grain, and producing flour at 3000 locations. That survey, called the Domes Day Survey, made no mention of windmills.

> Historical note on terminology: Water mills, which had been developed and operated during Roman times, were sometimes called corn mills, which can be confusing since corn as we know it, also called maize, was originally cultivated in the Americas and was not known to the Europeans until many centuries later. Corn, however, is also an English term for a small granule of grain (like a peppercorn), so a corn mill (also called a gristmill) could be used to grind peppercorns to a fine powder to season food.

Terminology notwithstanding, the gristmill or corn mill was an important device, whether operated manually in small, hand-driven devices or in a mechanized fashion with a water mill, windmill, or horse-driven mill. The milling process of the time was accomplished by two stones, one the bed stone with grooves in it and the other a runner stone that rotated on top, crushing the grain kernels and producing flour. The flour was driven to the outside of the bed stone by centrifugal force and captured in bags. Although the exact date is unknown, sometime in the twelfth century, the English post windmill was developed to grind grain. The post mill typically consisted of four wind vanes with canvas sail cloths, following technology similar to that of sails on a sailing vessel, which would drive a shaft and through gearing drive the millstone to produce flour. The mill was constructed on a “T” that could swivel, and a housing structure around it contained the mechanical equipment. A pole sticking from the back was used to align the windmill with the prevailing wind direction. On later models, a fan tail was introduced to mechanically do the same thing.

Records from the time show that, by the year 1200, the number of post windmills had grown rapidly in England. For example, on the Estates of Bishopric of Ely and located in a region of high grain productivity but low rainfall, a survey of the estates in the year 1222 showed four windmills. A subsequent survey done in 1251 showed 32 post windmills, while the number of watermills on the estates remained constant at 20. Although an inventory of the number of windmills throughout the country is not available, the growth was widespread and rapid (Fig. 1.14).

FIGURE 1.14 (a) Restored Post Mill, (b) Millstones, both from the American Wind Power Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the American Wind Power Museum in Lubbock, TX).

From an operational point of view, the water mill was actually preferred to the windmill because they were more easily controlled and could deliver power to the mill wheel on demand. Water mills had a sluice gate that could be opened and closed, controlling the flow of water to the water wheel and thus controlling the power delivered to the mill. The windmill relied on the speed of the wind, which was variable, and therefore capable of providing only intermittent power. However, many areas did not have water resources available and the only alternative was a horse-driven mill or the hand mill discussed earlier. In these locations, the adoption of the windmill was a welcomed alternative, and once introduced, grew rapidly.

The development of the post mill impacted communities in England in a number of interesting and probably unexpected ways. First were legal issues. During this time, if land owners had a stream or river on their property, they controlled the rights to that flowing source of power and any water mill erected was under the total ownership and control of the owners. However, in a well-documented case using church records, in 1190, a local church magistrate Dean Herbert erected a post windmill on his property to mill his own grain. Abbot Samson, another church official in the region but of higher authority (both the word “Dean” and “Abbot” are church titles from medieval times), had control of all milling operations and fees associated with those milling operations, and the fees were to be given to his monastery. According to church records, Abbot Samson became furious with the construction of Dean Herbert’s post windmill on the idea that he, the Dean, would grind his own grain without due compensation to the Abbot and the monastery. He demanded that the windmill be torn down and that people be sent from the abbey to carry out the task. Dean Herbert, according to documents at the time, made the first-known argument about the “wind rights” stating that, in fact, wind was free, owned by God and not man, and therefore he had the right on his property to build this device to capture the free power of the wind to grind his own grain without paying any fees. Although eloquent in his speech, Dean Herbert gave in and did in fact take down the post mill—but only after he had made these very strong arguments—with long-lasting effects. The references given in this section give excellent accounts of this exchange of Dean Herbert and Abbot Samson documenting one of the first legal arguments for the legal aspects of wind law (Source: Gimpel [2]).

With the number of post windmills growing, the impacts on the economy were substantial. Millwrights and land owners could build a post windmill and charge for grinding grain, with fees typically being 1/16 of the units of flour produced. Over time, the millwrights and windmill operators became people of prominence in their towns. Some of the windmills were so lucrative that land owners made enough money from the windmills to provide donations to the poor and to hospitals. In his book *Harvesting the Air, Windmill Pioneers in 12th Century England*, Kealey [3] points out that tithes on the profits of windmill operations were considered very suitable gifts for charitable and religious institutions of the period. For example, in about 1170, Reginald Arsic made a grant of a windmill to the monks of Saint Mary of Hatfield Regis. The original document exists with its original wax seal in the British Library. It states the following:

> Reginald Arsic, to all his men in the present and in the future, greetings. Know that I have given and granted and by this my charter have confirmed to the monks of Saint Mary of Hatfield Regis the whole **tithe of my windmill** which is in Silverly….

Windmills also became objects of art. Twelfth century windmill art was quite basic, using simple drawings and usually not very accurate. In later centuries, windmills became the subject for many romantic and pastoral scenes, especially for the Dutch landscape painters who found inspiration in both the large Dutch windmills and the English post mill.

Europeans were among the first to focus on using mechanical power for social development. They were concerned with efficiency, convenience, and entrepreneurship associated with the development of mechanical devices. In earlier times, the Romans who, although they had access to mechanical contrivances, mostly relied on human power to accomplish tasks with little regard for the idea of using mechanical devices to simplify and make easier the life of a common person. The European/English view is the one that is prevalent today with most people understanding that research in science and technology leads to advances in civilization and the concepts of efficiency, convenience, and entrepreneurship are well established. In addition to this overall social view of science and technology, there are a number of parallels in the development of wind power in twelfth century England to that of today.

As mentioned before, water mills for milling grain were directly controllable devices as long as there was water available. Windmills did not have that method of control and were subject to the variances in the wind. They could be shut down but never started up or increased in power beyond that available by the wind. The wind would change direction, requiring the millwright to change the orientation of the rotor in the wind. For these reasons, the water with its controllable power was preferred. Additionally, the fact that the mill and owner fully owned the water resources on the property meant that the landowner had complete monopoly on the water-milling operation.

By analogy, electricity-generating sources from the burning of fossil fuels can be controlled by changing the rate of fuel delivery to the power plant. It can be started, shut down, and controlled as desired. Wind turbines, on the other hand, can be shut down at any time, but the power level and the ability to deliver power are dependent on the wind speed, and yaw motors must be installed to align the wind turbine with the incoming wind direction to extract maximum power. Additionally, the fuel sources are owned and controlled by private enterprise whereas the wind turbine does not rely on any purchased fuel.

Also analogous is the use of twelfth century wind power as compared with the use of wind power today. As mentioned previously, flour used for bread and other food staples was a critical household commodity of twelfth century England. Today, electricity is the critical commodity—used throughout the industrialized world and depended upon to run households—from air conditioning and food refrigeration—commerce and industry. It is interesting that wind power, with all of its variability and use of an essentially free resource, was a key in producing a commodity staple, grain, in the twelfth century and a commodity product, electricity, today. The legal framework that wind operates under today in many ways had its roots back in the twelfth century with the examples of Dean Herbert and Abbot Samson discussed earlier in this section showing the origin of legal arguments related to wind power.

As development of the New World began in the seventeenth century, windmill technology from England and Continental Europe was imported for grain milling and water pumping. Because of its location and geography, Cape Cod is relatively flat with little flowing water. It is, however, quite windy, conducive to the installation

HISTORICAL MARKER
JONATHAN YOUNG MILL

BUILT CIRCA 1720 IN SOUTH ORLEANS, LATER MOVED TO THE CENTER OF TOWN. IT WAS MOVED TO HYANNISPORT IN 1897. IN 1983, THE STRUCTURE WAS GIVEN TO THE ORLEANS HISTORICAL SOCIETY BY THE GROVES FAMILY. THE SOCIETY THEN DONATED IT TO THE TOWN. DISMANTLED AND RETURNED TO ORLEANS, THE STRUCTURE WAS METICULOUSLY RESTORED BY VOLUNTEER LABOR, DONATIONS BY LOCAL BUSINESSES AND PUBLIC CONTRIBUTIONS.

FIGURE 1.15 (a) Restored Jonathan Young Mill in Orleans, MA. (b) Historical marker located at the site (Source: R. Walker).

of such windmills. Figure 1.15 shows a restored gristmill on Cape Cod in the City of Orleans, Massachusetts, including a short history of the mill shown on an accompanying plaque.

While taxes on revenue earned from windmills (such as that shown in Fig. 1.15) benefitted the community they were located in, the use of wind revenue for social projects, such as schools and hospitals, continues today with modern wind farm development. The photo in Figure 1.16 shows a new school in the West Texas town of Hermleigh, Texas, partially funded by tax revenue from the wind farm project in the background.

1.2.6 Wind Power for Industry

In addition to using the power of the wind to pump water and mill grains, many other repetitive industrial tasks were adapted to use mechanical power derived from the wind to replace human-, horse-, and waterpower. Several examples include the following:

- Sawing: In 1593, the first patent was issued in Holland for a wind-powered saw mill. Cutting timber was a laborious task and important for a number of commercial enterprises. This mill used a vertical saw blade and horizontal cart to carry the log to be sawed. Wind-powered saw mills were rare in Great Britain, with the first being built by a Dutchman in 1663 near London. The demand for wooden beams used in ship building was very strong at this time, and the mill caused a lot of

FIGURE 1.16 Hermleigh Independent School District, Hermleigh, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the Hermleigh High School in Hermleigh, TX).

interest. However, the local labor force of hand sawyers were strongly opposed and attacked the sawmill with axes. It stood abandoned for several years [2].

- Dyestuff and paper: Production of these materials required the stamping and hammering of wood and other materials. Early windmills converted rotary motion of the wind shaft to vertical stamping and pulverizing operations through a series of gears and shafts for these tasks.
- Oil mills: Oil could be extracted from the seeds of plants such as flax, rape, and olive by first crushing the seeds under edge runners, heating them, and taking them to a stamping operation for oil production.
- Mining operations: Windmills were used to provide power for ventilation and water-pumping systems in mines before the advent of the steam engine.

1.3 IMPACT OF ELECTRICITY ON SOCIETY

1.3.1 National Academy of Engineering: Great Achievements of the Twentieth Century

At the turn of the millennium in the year 2000, the US National Academy of Engineering (NAE), a group of renowned engineers in the United States, formed a panel to list the 20 greatest engineering achievements of the twentieth century. It was not a technical "gee-whiz" criterion that determined inclusion on the list, rather how

TABLE 1.1 National Academy of Engineering: Top Three Greatest Engineering Achievements of the Twentieth Century[a]

1. Electrification: Vast networks of electricity provide power for the developed world.
2. Automobile: Revolutionary manufacturing practices made cars more reliable and affordable and the automobile became the world's major mode of transportation.
3. Airplane: Flying made the world accessible, spurring globalization on a grand scale.

[a] Source: www.greatachievements.org
The complete list of the NAE's engineering achievements can be found at www.greatachievements.org.

much an achievement improved people's QOL. Former astronaut, Neil Armstrong, the first person to walk on the moon, presented the results and noted that "Almost every part of our lives underwent profound changes during the past 100 years thanks to the efforts of the engineers, changes impossible to imagine a century ago" (Table 1.1).

It is interesting that in this assessment by top engineers, electricity was named the technology that had the highest impact on society—not computers or rocket travel but delivery of electric energy to the homes, businesses, and factories of the world. Modern civilization would literally not be possible without electrification—from the preservation of food with refrigeration to heating and cooling of our homes to delivering light. Thomas Edison's development of the long-burning incandescent light bulb allowed people access to convenient, clean, and affordable lighting. As we will present in this course, electricity is provided from a number of sources through a vast and complex network delivering electrical power on demand. Presently, about one-sixth of the world's people do not have access to electricity. It is envisioned that the developments of renewable power sources and other advanced technologies will help bring electricity to these people and their communities. The modern wind power industry is presently the fastest growing source of bulk electric power and is seen by many to be poised to become a major contributor to delivering electric power worldwide.

1.3.2 History of the Early Electric Utilities

The first electric utility station was built in New York by The Edison Electric Company, founded by Thomas Edison in 1882. It was a power plant that produced direct current (DC) power and provided lighting to a small neighborhood in the New York City area. Between the years 1882 and 1886, there were major discussions as to whether the transmission of electric power would occur with DC or alternating current (AC). In 1886, Westinghouse erected in Great Barrington, Massachusetts, the first AC power station and transmission system. For a number of technical reasons, to be detailed later, the AC mode of electric utility transmission turned out to be the technology of choice and is in use today.

1.3.3 Rural Electrification Administration

In 1934, only about 11% of US farms had electricity. The United States was basically an agricultural economy at that time and providing electric power to farmers, ranchers, and livestock producers was seen as a key step in modernizing the

United States. In 1935, as part of the New Deal Act under President Franklin D. Roosevelt, the Rural Electrification Administration (REA) was formed to provide electricity to farmers, ranchers, and livestock producers within the United States. This would be accomplished through a series of rural electric cooperative companies. The REA was not well received by the private electric companies at the time since it was seen as a government intrusion in the area of private enterprise. However, due to the depression and the need for electric power, the REA moved forward and by 1942 50% of US farms had access to electricity mostly through rural electric cooperative companies and by 1952 almost all farms had access to electric power.

1.3.4 Expansion of the Electric Grid

The years following World War II began a time of rapid expansion of installed electric capacity in the United States. Figure 1.17 shows the capacity listed in millions of kilowatts or gigawatts (for reference, one gigawatt of capacity provides the electrical energy for about half million average households) and the growth from 1949 to 2009.

As shown in Figure 1.17, the United States crossed one terawatt, or a thousand gigawatts, shortly after the year 2000. Most of these power station installations are fueled by fossil fuels—coal and natural gas. The bulk of the renewable installations, especially during the 1950s and 1960s, were hydropower and the recent increase is mostly the addition of wind energy since most viable hydropower sites had been exploited by the mid-1970s. Nuclear power began to expand in the 1970s and now represents about one-fifth of the electricity supply in the United States.

Figure 1.18 shows the gross domestic product (GDP) and its increase during this same time period. It is not coincidence that the growth in electric capacity coincides with the increasing economic output of the nation, as represented by GDP. We will discuss in future sections the more complex relationship between these, especially as it has to do with energy efficiency, but in general one can link the increasing supply of electricity almost directly with the output of the national economy as represented by GDP.

1.3.5 Electricity—World View

- **The Relationship between Electricity Consumption, QOL, and GDP**

  We mentioned previously that access to electricity is an indicator of modern civilized society and the direct relationship between electricity supply and economic growth in the United States. In general, it can be shown that QOL indicators are highly correlated with energy use and in particular electric energy use. In recent years, social scientists and political leaders have determined a number of ways to measure QOL, from a “happiness index” in the country of Bhutan to other more quantitative measures that include such things as life expectancy, political stability, and wealth usually determined by GDP per person.

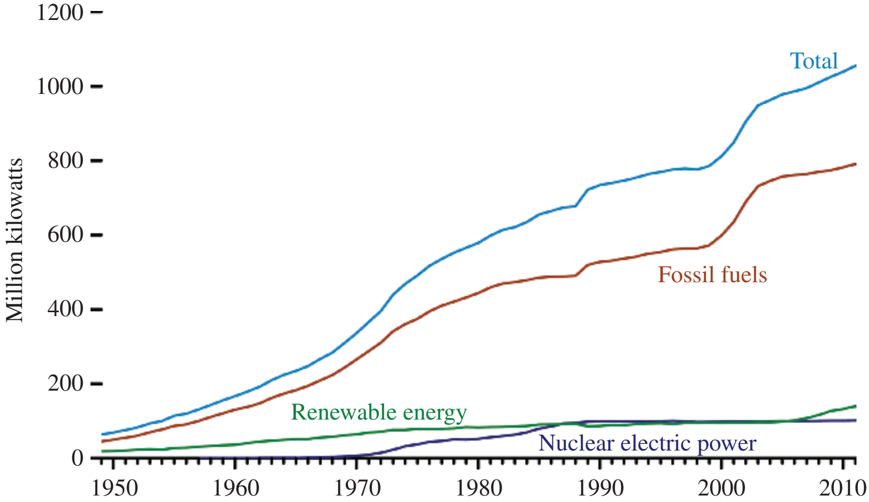

FIGURE 1.17 Installed Electric Generating Capacity by Source, 1949–2011(Source: US-EIA [4]).

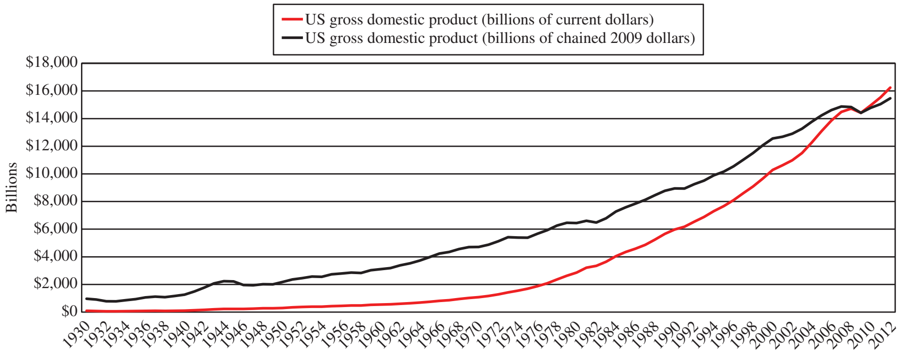

FIGURE 1.18 US GDP, 1930–2012, in billions (Source: R. Walker, based on data from the U.S. Bureau of Economic Analysis [5]).

The QOL index is based on factors including material well-being (based on GDP per person and purchasing power), health (based on life expectancy), political stability and security, family life (based on divorce rate), climate, geography, job security, political freedom, and gender equality. A comparison of this QOL index data with electric energy use per person for a number of countries is shown in Table 1.2, and the related correlation chart is shown in Figure 1.19.

The trend line shown in Figure 1.19 illustrates that, in general, as countries use more electricity per person, the QOL index increases. The data indicate that the increase is rapid at first and then is more gradual as more electrical energy

TABLE 1.2 Quality of Life Rankings Compared With Electricity Consumption[a]

Country	QOL ranking	QOL index	Population (millions)	GDP (at PPP) billion usd ($)	GDP (at PPP) per capita ($)	Electricity consumption (Gwh/year)	Daily kwh per capita	GDP (at PPP) per kwh ($)
Australia	6	7.90	21	803	38,238	257,247	33.54	3.10
Italy	8	7.81	58	1,827	31,500	359,161	16.95	5.10
Spain	10	7.73	41	1,402	34,195	303,179	20.25	4.60
USA	13	7.60	307	14,440	47,036	4,401,698	39.25	3.30
Canada	14	7.60	33	1,303	39,485	620,684	51.50	2.10
Netherlands	16	7.43	17	674	39,647	123,496	19.89	5.50
Japan	17	7.39	127	4,340	34,173	1,083,142	23.35	4.00
Taiwan	21	7.26	23	714	31,043	238,458	28.39	3.00
Germany	26	7.05	82	2,925	35,671	617,132	20.61	4.70
UK	29	6.92	61	2,236	36,656	400,390	17.97	5.60
Korea	30	6.88	49	1,338	27,306	443,888	24.80	3.00
Mexico	32	6.77	111	1,567	14,117	257,812	6.36	6.10
Brazil	39	6.47	199	1,998	10,040	505,083	6.95	4.00
Thailand	42	6.40	66	549	8,318	149,034	6.18	3.70
Philippines	44	6.40	98	318	3,425	60,819	1.70	5.20
Turkey	50	6.29	77	904	11,740	198,085	7.04	4.60
China	60	6.08	1,339	7,992	5,969	3,444,108	7.04	2.30
Vietnam	61	6.08	87	242	2,782	76,269	2.40	3.20
Indonesia	71	5.80	240	917	3,821	149,437	1.70	6.10
Saudi arabia	72	5.77	29	578	19,931	204,200	19.28	2.80
India	73	5.70	1,166	3,304	2,834	860,723	2.02	3.80
Bangladesh	77	5.65	156	226	1,449	35,893	0.63	6.30

Egypt	80	5.60	83	445	5,361	130,144	4.29	3.40
Iran	88	5.35	66	844	12,788	211,972	8.79	4.00
Pakistan	93	5.23	176	431	2,449	91,626	1.43	4.70
Russia	105	4.80	140	2,271	16,221	1,022,726	20.00	2.20
Nigeria	108	4.51	149	336	2,255	21,110	0.39	15.90
World			6,784	70,048	10,325	20,279,640	8.18	3.50

[a] Source: A. Swift based on *The Economist Intelligence Unit* [6], *CIA World Factbook 2009* [7], *Enerdata Statistical Energy Review* [8]; This graph is compiled of data from several sources.

Sources of data

- QOL index from *The Economist Intelligence Unit's Quality-of-Life Index, The World in 2005* [6], http://www.economist.com/media/pdf/QUALITY_OF_LIFE.pdf
- Countries listed are top 20 most populous countries and/or those in top 20 highest GDP as adjusted for purchasing power parity plus Saudi Arabia, based on *CIA World Factbook 2009* [7].
- *Enerdata Statistical Energy Review* [8], electric energy consumption data from 2009 for the 20 most populous countries.
- Productivity as a function of electricity consumption (a concept similar to energy intensity) can be measured by dividing GDP by the electricity consumed. The global average was $3.50 of production for every 1000 kWh of electricity consumed.

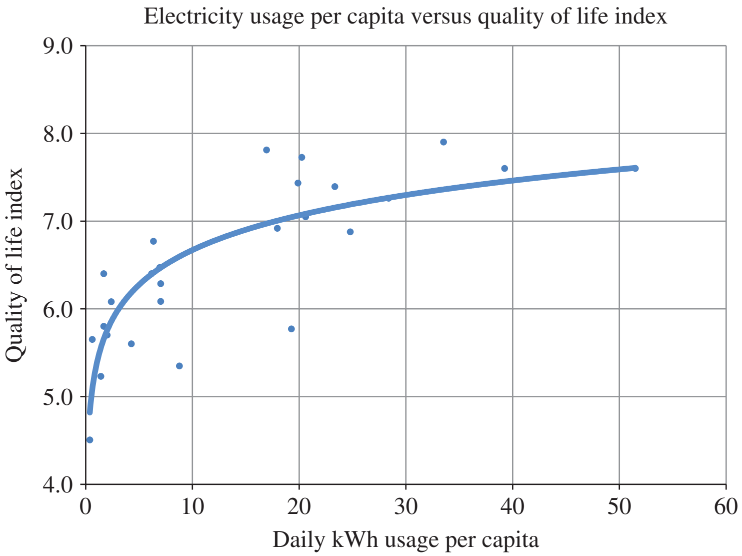

FIGURE 1.19 Chart Showing Quality of Life versus Electricity Usage per person from Table 1.2 (Source: A. Swift).

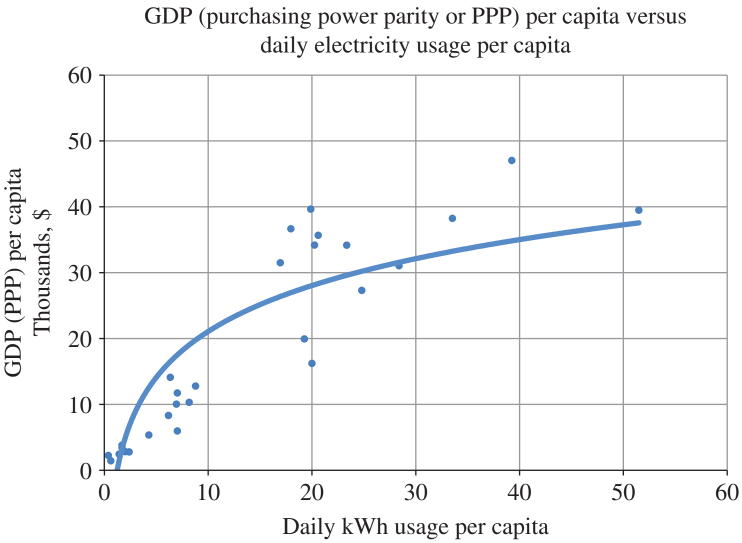

FIGURE 1.20 Chart showing GDP Purchasing Power Parity (PPP) per person and Electric Energy Use per person (Source: A. Swift).

per person is used. The rule is not absolute because such things as political stability can have significant effects on the QOL index, but in general the trend is clear. It can also be shown that GDP on a per-person basis is also directly correlated with electric energy use in a similar fashion as seen in Figure 1.20.

- **Role and Importance of Energy Efficiency**

If one were to forecast the growth in electrical energy requirements with world population growth to provide a basic level of electricity use per person, the need for additional electric-generating capacity would grow very quickly and is probably unsustainable using current electric generation technology. In other words, given our current mix of electric-generation sources, there are just not enough resources to provide all of the electric needs for the growing population of the world. This in fact is one of the motivations driving many people to look at changing the mix of energy supply to include more renewable energy sources, such as wind and solar energy—which are abundant throughout the world. Another way to provide electricity to a growing population is by producing, delivering, and consuming electrical energy resources more efficiently. Traditional energy sources that rely on thermal inputs, either burning of fossil fuels or the fission of nuclear material, are extremely wasteful processes, determined by the laws of thermodynamics. Typically, two-thirds of the heat energy of the source fuel is wasted in conversion to electricity, while one-third is converted to useful electrical energy. Modest increases in thermal power plant efficiencies can have a significant impact. These concepts will be covered more thoroughly in Chapter 15.

Additionally, if one considers the consumption of electricity (in other words, the end use—such as lighting, refrigeration, heating and cooling, and industrial processes) and improves the efficiency of these processes, mainly by delivering the same service for a reduction in energy consumption, this is also beneficial. The first is called supply-side efficiency, and the second is demand-side efficiency. Both of these strategies will allow a growing population access to electricity resources at reduced rates of growth for electric energy supply.

There are two metrics one can use to evaluate efficiency of electric energy production. One is the per capita use of electric energy, as we already looked at in the QOL chart. The other is electric energy use per unit of GDP—in other words, how much electricity is used to drive the economy. Efficiency of electric energy use can be a major determination in calculating the quantities of electric-generating capacity and consumption of resources for electricity generation to meet the given demand. For example, if one uses the maximum electricity consumption per capita number from Table 1.3 and applies population growth from the current time to the year 2050, one can project the estimate of the maximum amount of electrical energy required at that time. Similarly, using the minimal energy per person value at the same QOL, one can project a second, lower-level of required energy capacity. If these limits are combined with increases in electrical-generation efficiency and a transition to renewables, one can begin to understand the range of projected future electricity needs not only for the two billion people who do not have access to electricity but also for providing a reasonable QOL for the growing population of the world.

- **Jevons' Paradox**

  In 1865, William Jevons, an English economist, produced a book called *The Coal Question,* where he examined the use of coal in England. During that period, coal was the primary energy source and Jevons observed that the consumption of coal greatly increased after James Watt introduced the coal-fired steam engine, which was a great improvement in efficiency as compared with Thomas Newcomen's earlier design. At the time, many in England worried that coal reserves were decreasing rapidly and many argued that increasing the efficiency of use would reduce coal consumption. Jevons argued that was not correct. In fact, the increase in efficiency, as with the use of Watt's steam engine, would increase the use of coal since the improved steam engine delivered less expensive power and more people could therefore afford to use it, requiring more steam engines to be built. Modern energy economists have pointed out that Jevons' Paradox applies only to technological improvements that increase fuel efficiency but that the imposition by governments of conservation standards that simultaneously increase costs do not necessarily cause this paradoxical increase in fuel use. Recent examples of such government initiatives include a green tax, a carbon tax, cap and trade, license fees, and so forth, which, it is argued, would counter Jevons' Paradox. However, such regulations have been met with resistance by those who feel energy markets should use a free market approach to set the price of energy.

1.4 HISTORY OF WIND ENERGY FOR ELECTRICITY PRODUCTION

We saw in the previous section the importance of access to electrical power for improving QOL and prior to that the importance of programs such as the REA in providing electricity to rural America in the 1930s. In this section, we will review the history of wind power development for electricity production with a focus mainly on the United States. It should be pointed out that the use of wind power generation proceeded rapidly during the twentieth century in countries such as the Netherlands, Denmark, Russia, and Germany during this same time period, and thus, there are really two histories of wind power development for electricity. The first US wind-driven electric generator was installed in the late 1800s by Charles Brush in Ohio. He built a large wooden wind turbine with a DC generator and a series of batteries to provide electricity for his home. In the 1920s and 1930s, a number of small companies were developed to produce wind generators to charge batteries and power lights and radios for locations without access to grid power. Typically, these locations were in the Great Plains, prior to the REA's program, where the persistent winds provided a reasonable means to provide basic electric power (Fig. 1.21).

The most successful company of this period was the Jacobs Wind Company, which produced thousands of wind generators for home and ranch use. The Jacobs turbine was very rugged and, in fact, was taken to the South Pole to provide electricity for an expedition. It was installed and provided power for the expedition and then left

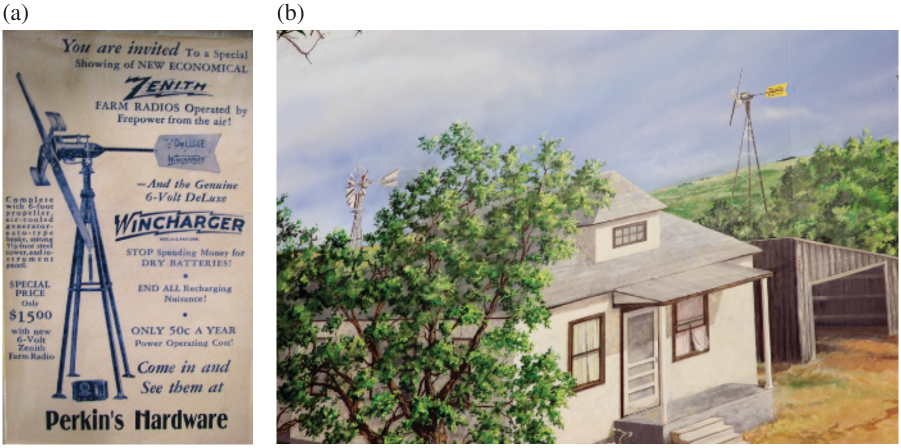

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FIGURE 1.21 Advertisement (a) and painting (b) of Zenith Wind Charger at ranch home before REA. Photo—reproduction from wall mural at the American Wind Power Center, Lubbock, TX (Charles Norland, Norland Photographic Art, St. Louis, MO. Picture taken at the American Wind Power Museum in Lubbock, TX).

for several years until the next expedition came back and found it still in working condition. There were plans to put a series of these small turbines on or near electrical lines and provide larger-scale power; however, these ideas never came to fruition as the REA put these companies out of business.

In 1942, a group led by Palmer Putnam designed and installed a large grid-connected wind turbine—the first utility-scale wind turbine connected to the utility grid in the United States. His book, *Power from the Wind,* is an excellent overview of how that project was conceived and developed. The turbine operated for several years, and during a windstorm one evening, one of the blades experienced metal fatigue, broke, and flew off and down the mountain. Since the turbine operator rode in the small cabin at the top of the tower, he experienced a very exciting ride as one blade came off, and due to the imbalance, swung around the top of the tower until he could shut down the turbine. Since World War II was under way at the time, there were insufficient funds and interest in repairing the turbine and thus the project was stopped. After the war, the price of oil and other fossil fuels declined considerably and access to the fuels was readily available. Thus, the idea of using wind power to generate utility electric power was abandoned (Fig. 1.22).

In 1970, there was an oil embargo from the Organization of the Petroleum Exporting Countries that led to an energy crisis in the United States. That event caused a major reexamination as to the dependence of the nation on fossil fuels, especially imported oil, which was a major source of electricity production at the time. During that period, the Department of Energy (DOE) was formed to make the United States independent from foreign energy supplies. One of the technologies that the DOE took very seriously was utility-scale wind generation. In the 1970s and 1980s,

FIGURE 1.22 The 1.25 MW Smith–Putnam Wind Turbine of 1942, the first utility-scale, grid-connected wind turbine in the United States (Photo from the archive of Carl Wilcox in the possession of Paul Gipe).

there were a number of designs produced by researchers both within and outside the DOE. Shown in Figure 1.23 are DOE turbine designs. The first wind farm was located in California.

Wind farms are large groups of wind turbines connected to the grid to generate electrical power. California rapidly grew to become the leading state in installations of wind power in the 1980s. A number of excessively lucrative tax credits in California at the time led to the installation of equipment that was not very reliable and often inefficient, leading to high costs of electrical generation and unreliable production. The California tax credits were tied to equipment installation rather than to how much electricity the equipment produced. In the early 1990s, a federal Production Tax Credit was put in place. At about that same time, a number of Deliberative Polls® taken by utility companies in states including Texas and Louisiana showed that, in general, people were very supportive of wind power and renewable energy. This led to the formation of statewide renewable portfolio standards in several states, including Texas, mandating that a certain fraction of electrical energy be produced from wind power or other renewables. This, along with the entry

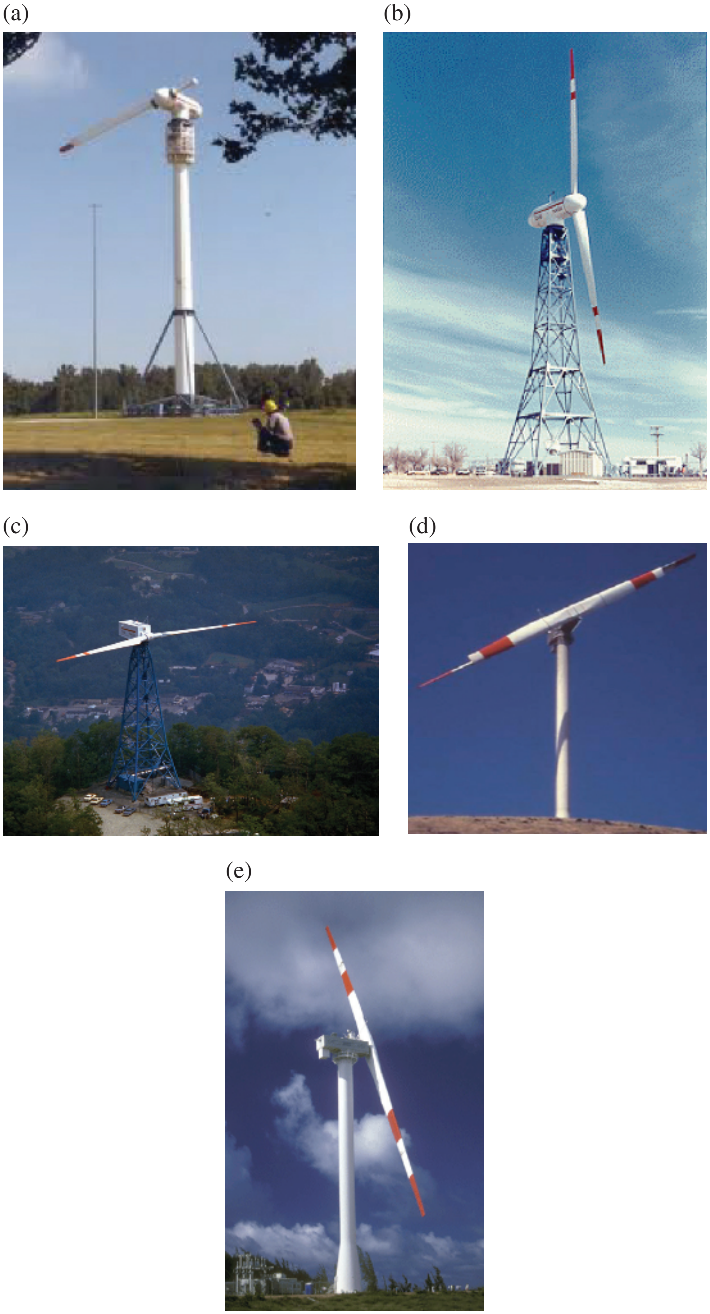

FIGURE 1.23 US DOE Wind Turbine Designs. (a) DOE-NASA MOD-0 (1974-75) One-bladed rotor configuration; Sandusky, OH, (b) 200 kW DOE-NASA MOD-0A (1977-81) 38 m rotor diameter; Clayton, NM, (c) 2 MW DOE-NASA MOD-1 (1979-81) 61 m rotor diameter; Boone, NC, (d) 2.5 MW DOE-NASA MOD-2 (1982) 78 m rotor diameter; Goodnoe Hills, WA, and (e) 3.2 MW DOE-NASA; MOD-5B (1991); 97.5 m rotor diameter, variable speed (13–17.3 rpm) Built by Boeing; Kahuku, HI (Source: US DOE).

into the industry of large US companies such as General Electric, combined with rapid advances in Denmark, the Netherlands, and Germany formed the foundation of the modern utility wind industry.

1.5 RENEWABLES AND ELECTRIFICATION IN THIRD-WORLD COUNTRIES

As discussed previously, many people in the world do not have access to electrical power. As solar photovoltaic technology and wind technology have improved, especially on a smaller scale, access to electric power in Third-World countries has been growing. Although solar and wind technologies in remote areas tend to be relatively expensive, the costs are substantially cheaper than the installation of large electric-generating stations and a network of transmission lines to deliver power to remote areas. These stand-alone remote systems have been instrumental in delivering power to many parts of the Third World.

1.6 THE NEXUS OF WIND, WATER, AND ELECTRICITY

Thermal power generation uses large quantities of water for cooling. In fact, the annual withdrawal of water to provide cooling for thermal power plants is the largest use of water in the United States. In arid areas where water is limited or underground wells are used to provide water, these withdrawals (and related consumption of water) can limit the installation of power plants to provide electricity. Additionally, since underground water in arid areas is typically consumed at rates higher than underground aquifers can be recharged, these resources are not sustainable over long periods. Wind energy generates electricity without the use of water, which is a significant advantage when compared with thermal generation sources. These issues will be discussed in greater detail later in the text.

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