CHAPTER ONE

Overview of Energy Usage in the United States and the World

To begin, take a moment to stop and listen. Try to observe all sounds: the tick of a clock, the hum of a computer, the whirl of a passing car, the whisper of a heater, or perhaps the growl of an airplane overhead. These sounds, so common that they often go unnoticed, would likely sound thunderous to societies living 200 years ago. What makes society today so different from those historical societies? The answer is simple: **fossil fuel**.

The availability of easily accessible and cheap energy has breathed technological life into society. It has influenced the way we transport ourselves, the houses we live in, the offices we work in, the classrooms we study in, and even the food we eat. Energy has single-handedly changed the face of society from one of short walking commutes, locally farmed foods, and face-to-face personal communication to a society where travel distances are unlimited, fresh foods are always available regardless of season, and communication, over even vast distances, is instantaneous and done using battery-operated handheld devices. Although these technological changes have led to a society of convenience, they have not come without cost to our energy supply, our food security, national security, and the environment.

Today, fossil-fuel-based energy is critical to sustaining the lifestyle that many countries have become accustomed to. And the numbers can be overwhelming; today in 2015 we burn 93 million barrels of oil per day, or 1.4 trillion gallons of oil per year, and oil is only about one-third of the energy we consume every year. To maintain this level, let alone allow for increased energy use, we will need to develop new alternative sources of energy if we are going to preserve this lifestyle and prevent further reduction to energy supply, security, and the environment. As a basis for this entire book, this introductory chapter will explore the basic concepts of energy production and utilization and its critical role in modern society.

Understanding Energy

Energy, by definition, is the ability to do work on a physical system. Yet, what does this really mean? Since energy is the capacity to do work, one must first understand the concept of work. Work is defined as force multiplied by distance. A force alone is not enough to constitute work; it must be combined with a movement, a term equivalent to the distance component of the equation. Consider the example of someone pushing a shopping cart and running into a wall. No matter how hard this person pushes the cart or how much force he or she exerts, if the cart is not changing position then no work is being done. Therefore, a source of energy needs to allow for both force and motion. In addition, this energy source must be replaced to maintain the work that is occurring. The energy is replaced in a car by filling the tank with gasoline, or in a body by eating food, such as an apple. The apple is a source of energy because it provides nutrients powering the body with food calories and allowing for continued work.

Energy is measured in many different ways. In the previous example of food, energy was measured as the number of food calories in the apple. Food calories are really kilocalories (and take the capitalized form, Calories); one Calorie is equal to 1,000 calories. A calorie is defined as the amount of energy that will raise the temperature of one gram of water by one degree Celsius. In addition to the food calorie and calorie, there are many other metrics of energy important to our understanding of the concept of energy as shown in Table 1. Energy is often measured in terms of joules. A joule is equivalent to a Newton times a meter (remember force times distance). In this book, energy will also be referred to in British thermal units (BTU). A BTU is equivalent to 1,055 joules and is often used when discussing energy sources used to heat water or other substances. In many cases, energy is produced or consumed at such a

TABLE 1
Energy conversion units

	J	kWh	BTU	kcal
1 joule (J)	1	2.8×10^{-7}	9.5×10^{-4}	2.4×10^{-4}
1 kilowatt-hour (kWh)	3.6×10^{6}	1	3,412	860
1 British thermal unit (BTU)	1,054	2.9×10^{-4}	1	0.252
1 kilocalorie (kcal)	4,184	1.2×10^{-3}	3.97	1
1 tonne oil equivalent (toe)	4.5×10^{10}	11,630	4.2×10^{7}	1.1×10^{7}

NOTE: Each publication may discuss energy in terms of different units such as J, BTU, kcal, kWh, and toe. This table is designed to help understand the relationship between these units and allow for the conversion between different energy-related units.

DATA FROM: APS Panel on Public Affairs (2014).

TABLE 2
Comparison of energy content for varying energy sources including fossil fuels and common food sources using differing units of comparison

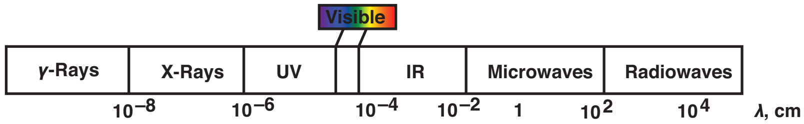
	J	kWh	BTU	kcal
1 barrel oil (42 gallons)	6.1×10^{9}	1,713	5.8×10^{6}	1,468,800
1 ton coal	2.7×10^{10}	7,560	2.5×10^{7}	6,480,000
1 therm gas	1.1×10^{8}	29	1.0×10^{5}	25,200
1 gallon gasoline	1.3×10^{8}	36.0	1.2×10^{5}	31,248
1 bushel corn (56 pounds)	8.6×10^{7}	24.5	8.1×10^{4}	20,453
1 fast-food hamburger	2.8×10^{6}	0.8	2.7×10^{3}	670

DATA FROM: APS Panel on Public Affairs (2014); US Department of Energy (2014).

large scale that a very large standard of measurement is needed. An example of such a large consumption of energy is the consumption or production of fossil fuels around the world. Energy on this very large scale is often measured by comparing it to the burning of 1 ton of petroleum also known as a tonne of oil equivalent (toe). One toe is equivalent to about 42 gigajoules of energy (APS Panel on Public Affairs, 2014). In order to get a better grasp on how these various energy measurements relate to one another, Table 2 shows energy equivalents of some common energy sources.

The various ways of measuring energy are due in large part to the many different forms of energy. There are fundamentally five forms of energy: chemical, electromagnetic, mechanical, nuclear, and electrical. The first form of energy, **chemical energy**, is energy that occurs due to a chemical transformation or chemical reaction. The notion of a chemical reaction might bring to mind a picture of flasks containing colored liquid bubbling over a Bunsen burner. Nevertheless, chemical energy is actually quite varied and common, and includes things like burning wood in a campfire for warmth or eating a slice of pizza to satisfy one's appetite. In the case of burning wood, coal, or any other substance, the solid wood or coal is broken down and heat and ash are created. As the chemical bonds are broken within the wood or coal, energy is released in the form of heat. This heat can be used simply for direct warmth or it can be used to heat another substance like water to produce steam, a key reaction in the production of electrical power. Although a slice of pizza is not burned in the same way that wood or coal is burned, it is also broken down through digestion into smaller components like amino acids, carbohydrates, and lipids, changing the pizza's chemical state. This change in chemical state results in the biological components needed for metabolic respiration and the creation of adenosine triphosphate (ATP), a molecule that provides fuel for the reactions occurring within the body.

Electromagnetic energy is another form of energy. Electromagnetic energy (or radiation) is the energy of light. Most of the natural light received on Earth comes from the sun. Electromagnetic radiation results from oscillating energy particles called photons moving in wavelike patterns. These photons are a result of thermonuclear reactions that occur within the core of the sun and then radiate outward toward the Earth. Depending on the amount of energy these pho-



Gamma (γ-Rays) – Nuclear Fission and Fusion
X-Rays – Diagnostic Radiology
Ultraviolet (UV) – Formation of Vitamin D and Sunburn
Visible – Photosynthesis and Light
Infrared Radiation (IR) – Heating, Night Vision, and Short Distance Communication (Remote Controls)
Microwaves – Communication, Radar and Power
Radiowaves – Communication

FIGURE 1.1 Chart showing the wavelength ranges for the various particles of electromagnetic radiation. The amount of energy contained within each of these particles varies based on this wavelength. The longer wavelengths have less energy, while the shorter wavelengths have more energy. Each range of wavelengths has a unique name that can also be associated with different and unique functions. For instance, ultraviolet wavelengths cause sunburns, while radio wavelengths are used for communication.

tons contain, the wavelengths change and they are classified as different types of radiation as shown in figure 1.1. For instance, wavelengths classified as visible radiation (visible light) allow human beings to see colors, while wavelengths classified as ultraviolet radiation cause their skin to sunburn at the beach. Electromagnetic radiation is very important to the balance of the Earth not just because this energy source provides light but also because it provides heat. Chapter 3 will cover how electromagnetic energy enters the Earth's atmosphere and how a significant portion of it becomes trapped within the atmosphere. This trapped energy is what gives the Earth its mild temperatures and one of the factors that allows life to be sustained on this planet.

Another important form of energy is mechanical energy. **Mechanical energy** is often classified into two categories: potential and kinetic. **Potential energy** is the energy of an object due largely to its position in relation to the force of gravity, while kinetic energy is the energy of motion. Take, for example, a rollercoaster. Many know the gut-clenching feeling brought on by the click, click, click sound as the rollercoaster car is brought up to the summit of the first big hill. When this car is sitting at the top of the hill, it has a lot of potential energy. The car has the "potential" to roll down the hill due to gravitational forces and thereby gain great speed. As the rollercoaster car accelerates down the hill, it transfers the potential energy into **kinetic energy**. Since kinetic energy is the energy of motion, the faster the car moves, the more kinetic energy it contains. You can also think of kinetic energy in terms of an automobile accident. A car that crashes while moving slowly does not suffer nearly as much damage as a car going extremely fast. The fast car has more kinetic energy meaning that more energy will be used to damage the car when it comes to an abrupt stop.

Nuclear energy is another form of energy that is important to society. Nuclear energy results from reactions that change the structure of an atom's nucleus. Nuclear reactions occur in the interior of the sun and in the interior of the Earth as well as in nuclear reactors used for energy production. The first type of nuclear reaction is the fusion reaction. This reaction takes place in the sun and occurs when two atomic nuclei fuse to form a single atomic nucleus such as two hydrogen nuclei combining to form a helium atom. The second reaction is the fission reaction. Fission reactions take place in nuclear power plants and, in this case, the nucleus of a single atom breaks into two atoms such as when uranium splits apart. Both of these reactions are capable of releasing a lot of energy; thus, they are an important component in the consideration of sustainable energy development. Nuclear energy will be discussed in more detail in Chapter 4.

The final form of energy is **electrical energy**. Atoms are made of subatomic particles that include positively charged protons and neutrally charged neutrons within the nucleus, and negatively charged electrons floating around the edges of the nucleus. Electrical energy occurs when electrons are passed from one atom to another, and this occurs when an electric field is applied to metals. Because all electrons are negatively charged, they repel one another. By maintaining this repulsive relationship down a wire, these electrons create an electric current. Once the electrons make it to a resistor, they react with the atoms within the resistor releasing either heat or a magnetic field. This final release of heat or creation of a magnetic field is what results in power generation. There are several ways to generate electricity, including renewable sources like wind, solar, and water, and these will be discussed in a later chapter. However, one essential concept of electrical energy is that this energy source must be used immediately. Electric energy must be consumed as it is produced or it simply dissipates as heat. Storage of electrical energy in batteries is possible, but as many of you know, batteries are able to store only limited amounts of energy and must be recharged often.

All of these energy sources play an important role in modern society. Yet, to really understand the value of energy, one cannot consider these forms of energy individually but must consider them as a whole. The reason for this is due to the **First Law of Thermodynamics**. This physics law states that *"energy can neither be created nor destroyed; it can only be transformed from one state to another."* This means that all of these various forms of energy are not individually being created but rather they are simply energy in one form that is being converted to another form. Let us consider a couple of examples. Thermonuclear reactions within the interior of the sun release electromagnetic energy from the creations of new atoms by nuclear fusion. This energy travels to the Earth via photons (electromagnetic radiation energy), and these photons can be absorbed by chlorophyll in plants, such as in the leaves of trees. The trees use the energy from these photons to fix carbon dioxide and produce sugar that eventually becomes the wood of the tree. This wood can then be burned to create heat for a home or to produce steam to drive a turbine. In this energy transformation example, the nuclear energy from the sun becomes electromagnetic energy in the form of photons and then becomes chemical energy in the form of wood. Another example that can be considered is hydroelectric power generation. In this case, the electromagnetic energy in the form of photons heats the Earth's atmosphere, causing the evaporation of water, which in turn forms rain or snow. This snow melts or rain fills up a lake located behind a dam where the water represents potential energy. As the water travels from the top of the dam to the bottom of the dam through a tunnel, the potential energy is converted to kinetic energy that can be used to turn a turbine. The turning of the turbine generates an electric field that creates electricity, which travels to homes to power electrical devices. These examples demonstrate how energy is never created nor destroyed; it is just transferred from one form to another. The First Law of Thermodynamics is not to be confused with what we call "energy production." Energy production is not the same as energy creation. In energy production, people go out and find an energy source that already exists and then extract this source. Once extracted the source can be converted into other types of energy resources. Most of the energy produced in the world is derived from fossil fuels including petroleum, coal, and natural gas, all resources already available, and all we really do is extract these existing energy sources from the Earth.

The First Law of Thermodynamics is very critical in understanding energy and the development of renewable energy sources because there are a limited number of primary sources that transfer energy on to the surface of the Earth. These include nuclear, solar, geothermal, and tidal energy, which will be discussed further in Chapter 4. All other energy sources including fossil fuels are ultimately derived from one of these four sources. Three of these primary energy sources (solar, geothermal, and tidal) represent another key concept, renewable energy. **Renewable energy** is defined as energy that comes from one of the primary sources. The ideal renewable energy source is also sustainable meaning that the resource will be replenished with-

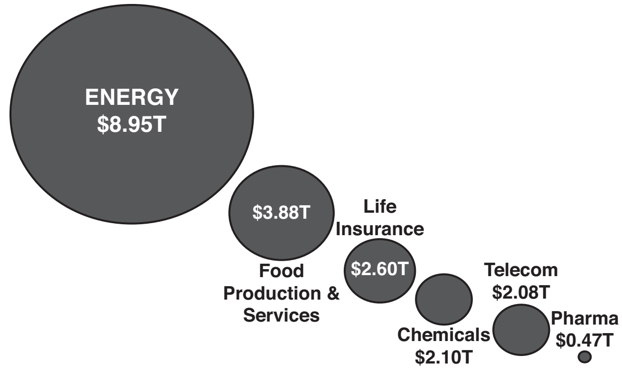


FIGURE 1.2 Comparison of market values for large industries around the world. The world's energy market valued at an estimated $8.95 trillion is over twice as large as the food production and services market valued at an estimated $3.88 trillion. The energy market also dwarfs other large markets including life insurance, chemicals, telecom, and pharma. As the energy market continues to expand, we will likely see an even greater separation of value (data from Bloomberg, 2014).

out a detriment to the environment. While solar, geothermal, and tidal energy are considered both renewable and sustainable, nuclear energy still has significant environmental issues. Although elements such as uranium that are used in nuclear reactions are not replenished on the Earth, the resources of these elements on Earth are very large and the amount of energy generated is so high that it is believed that nuclear energy will be available for thousands of years, leading many people to mistakenly consider nuclear energy a traditional sustainable source. Like hydroelectric, photovoltaic, and wind energy, bioenergy is directly produced from solar energy and is therefore a renewable energy source.

Energy, Population, and Standard of Living

Energy is one of the most influential and important aspects of modern society. To understand the magnitude of its importance, consider its value economically. By comparing the energy market to other major markets such as food production, telecom, and insurance as shown in figure 1.2, one can begin to understand the incredible value of energy. Energy is easily the largest global market valued at nearly $9 trillion worldwide with other large industries ranking well below this enormous number (Bloomberg, 2014). The value of energy in the United States is also very large at $1.2 trillion, roughly one-tenth of the gross domestic product (GDP; US Department of Commerce, 2012). In addition to its huge raw value, the energy market also literally fuels many other markets, resulting in its value to the United States and world economies being much higher. As the world's largest market, energy is a main driver of the world's economy.

Despite its enormous value, the world's energy market is not stagnant, nor has it reached a plateau. As an example, the US energy market is expected to increase in value from $1.2 trillion in 2010 to $1.7 trillion in 2030, an increase of about 30% in 20 years (US Department of Commerce, 2012). The world energy market will increase at an even faster rate, largely due to an expanding population and an increase in the standard of living around the world. The world's population is currently over 7 billion and is expected to reach 8 billion by 2030 (US Census Bureau, 2012). As more people populate the Earth, more energy is consumed to sustain the population with basic resources such as food, transportation, and housing. All of these basic resources have become critically dependent on the availability of energy resources. Even if the world's population were to plateau, the energy market would continue to increase due to the link between energy and standard of living. An indicator of a country's standard of living is its **GDP** per capita. The GDP of a country represents the value of all goods and services produced in that country, thus indicating a country's wealth. When this overall wealth is divided by its population, a rough estimate of the standard of living for individuals within that country results. For example, a large developed nation like the United States has an annual GDP of about $15 trillion and a population of about 307 million, giving the United States a GDP per capita of $48,859. We can then compare this to a large developing nation such as China. China has an annual GDP of almost $6 trillion and a population of about 1.3 billion people, giving China a GDP per capita of only $4,615 (CIA, 2012). Since the GDP per capita roughly estimates the annual income available to individuals, it is clear that the standard of living in the United States is much higher than that of China. Again, there is a link between standard of living and energy use per capita where a higher standard of living equals a higher use of energy per capita. Figure 1.3 compares primary energy consumption per capita to the GDP per capita of many countries around the world. This graph shows that countries with high standards of living (measured as high GDP per capita) including Qatar, Singapore, Norway, and the United States are also some of the highest primary energy consumers, while nations with lower GDP per capita such as China, India, and Egypt are also the nations that consume the least amount of energy per capita.

While this comparison of GDP per capita to primary energy consumption gives insight into how some countries are able to maintain much higher standards of living than others, it also offers a preview of what the future of energy consumption may entail. Countries such as the United States have set the bar high for standard of living and many other countries want to reach that same standard. Envisioning a world where all people are living in conditions similar to the United States in terms of food availability, housing, and water availability may seem like an ideal situation, but this lifestyle will have a significant impact on energy use. As an example, China's economy is growing, which will ultimately lead to a higher standard of living for the people of China; however, as China's economy grows, so does its use of energy. The BP Statistical Review of World Energy states that developing nations like China and India accounted for 90% of the net increase in energy consumption in 2012 and China's use of energy increased by 11.2% between 2009 and 2010 (British Petroleum, 2011, 2013). Many other countries are also seeing a rise in energy consumption as the people in these countries gain better living conditions. The huge use of energy in countries with high GDP per capita and the growing use of energy in those countries with increasing GDP per capita represent a significant challenge for the future of energy production and utilization, and enormous challenges for the environment. Worldwide fossil energy sources are finite and getting more expensive to extract every day. In order to balance a growing population with the energy needs of higher standards of living around the world, it is critical to develop new technologies enabling the more efficient use of fossil fuels, while we simultaneously develop renewable resources to supplement and replace the finite fossil energy resources.

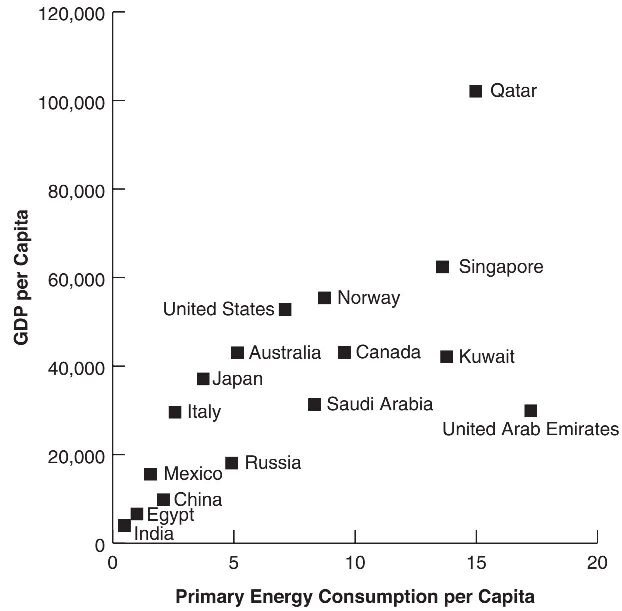


FIGURE 1.3 Graphical comparison of worldwide gross domestic product (GDP) per capita to primary energy consumption per capita, 2013–2014. This comparison provides evidence for the link between the consumption of energy and a higher standard of living. Many countries that consume higher levels of energy such as Qatar and Singapore also have a much higher GDP per capita. Countries such as Egypt and India have low primary energy consumption per capita and a low GDP per capita. A higher GDP per capita is associated with a higher level of income within each household (data from CIA, 2014; British Petroleum, 2014).

Energy Resources Today

Today, a majority of the world's energy **consumption** comes from fossil fuel sources including coal, natural gas, and petroleum as shown in figure 1.4. Together, these sources make up about 87% of all energy used in the entire world. The remaining 13% of energy consumption is derived from alternative energy sources including nuclear, hydropower, and other renewable sources (British

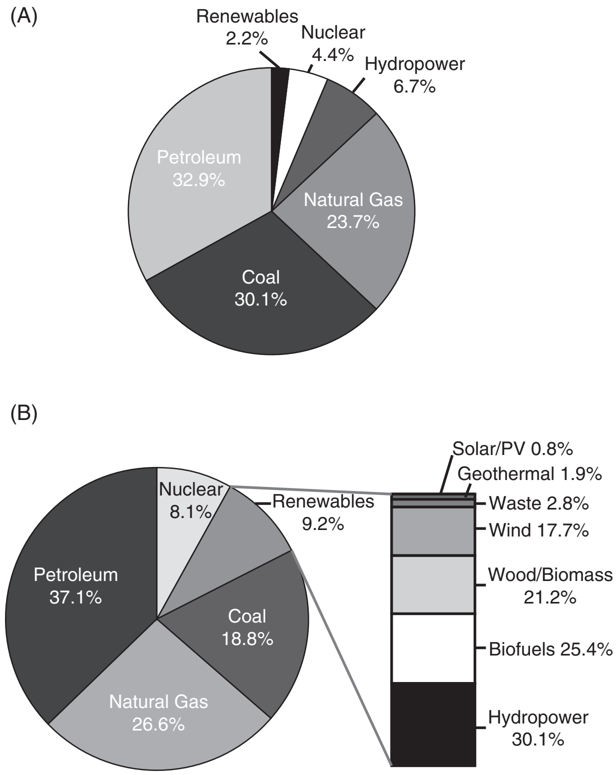


FIGURE 1.4 Comparison of world (A) and US (B) energy consumption by energy source. The fossil fuels including oil, coal, and natural gas dominate both global and US energy consumption at 86.7% total consumption and 82.5% total consumption, respectively. In the United States, renewable resources like hydropower, biomass, biofuels, and wind make up 9.2% of energy consumption (data from British Petroleum, 2014; EIA, 2014a).

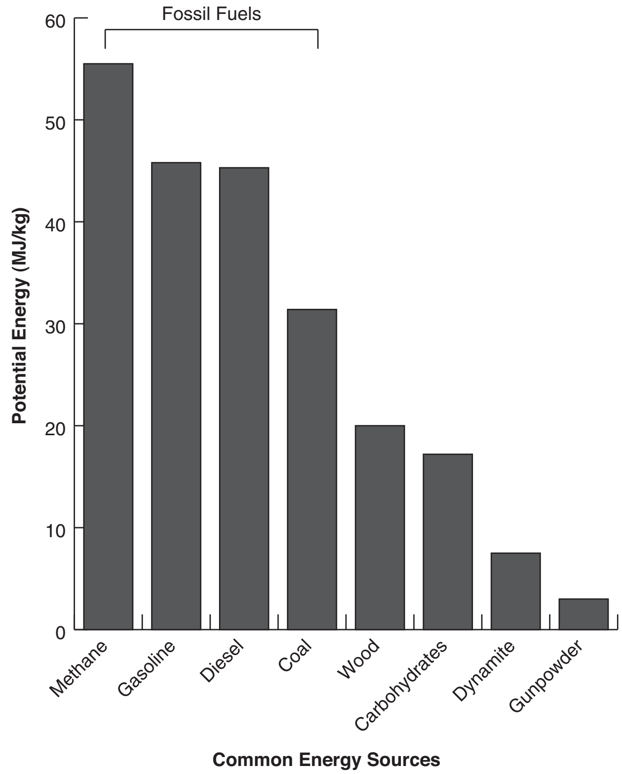


FIGURE 1.5 Graphical comparison of chemical potential energy levels among common energy sources. Fossil-fuel-based sources and products are the most energy dense of these substances (data from Elert, 2012).

Petroleum, 2013). The energy consumption patterns in the United States are similar to that of the world where 82.5% of energy consumption is from fossil fuels. It is apparent that the use of non-hydropower renewable energy sources in both the United States and the world is minimal at only 6.4% and 2.2%, respectively. The US energy consumption graph shows the breakdown of renewable energy consumption as spread between these different resources including solar, photovoltaic, geothermal, energy from waste, wind power, biofuels, and wood (EIA, 2014a).

Fossil fuels dominate the energy market largely because they are energy dense and historically relatively cheap. Figure 1.5 shows a comparison of energy density for a few common energy sources including fossil fuel resources, carbohydrates, and explosives (Elert, 2012). As shown by this comparison of energy per kilogram of material, fossil fuels are considerably more energy dense than even substances thought of as very powerful such as dynamite or gunpowder. Another advantage of fossil fuels is that they are relatively cheap. Compare the petroleum product gasoline to that of a common college food, pizza. One gallon of gasoline contains 116,275 BTU of energy and costs about $3.50. To get the same amount of energy from pizza, one would have to eat over 108 slices and it would cost about $220. While this much pizza is undoubtedly out of the price range of an average college student, buying a gallon of gasoline is often not a problem. This simple comparison clearly illustrates how on a price per unit energy basis, fossil fuels are much cheaper than most products including the food people eat.

Competitive pricing and high-energy densities have resulted in a steady increase in the consumption of all three fossil fuels both around the world and in the United States. In 2012, the United States consumed about 17.4 quadrillion BTUs of coal, 25.9 quadrillion BTUs of natural gas, and 32.5 quadrillion BTUs of petroleum. These figures are drastically higher than the consumption levels in 1950 of 12.3 quadrillion BTUs of coal, 6.0 quadrillion BTUs of natural gas, and 13.3 quadrillion BTUs of petroleum. This increase of 41.5%, 331.7%, and 144.4% for coal, natural gas, and petroleum, respectively, is largely due to the development of technologies heavily dependent on the use of these fossil fuels such as personal cars, individual home climate control, and the many electrical devices people have come to rely on every day (British Petroleum, 2013). Obviously, these increases in consumption have also required a steady increase in **production** of each of these fossil fuels. Figure 1.6 shows a comparison of production and consumption levels of petroleum in the United States since 1950.

AMERICAN ENERGY CONSUMPTION

Travis L. Johnson

It can sometimes be hard to understand the magnitude of energy consumption. For example, in 2014 the United States consumed nearly 95.5 *quadrillion* Btu of energy. Part of that annual consumption included about 7 *billion* barrels of petroleum, roughly 19 *million* barrels of oil a day, or 300 billion gallons per year. For ease of understanding, let us round that up to 20 million barrels per day and assume a US population of 300 million. This equates to every American getting a barrel of oil delivered to them every 15 days! As oil represents only about 35% of the overall energy consumption, if we include the remaining 65% as equivalent barrels of oil, Americans would receive a barrel of oil every five days. To put this another way, a barrel of oil has about 6 gigajoules of energy. If you divide that energy by the number of seconds in five days, you have the average amount of power an American uses in a day, a staggering 10,000 watts. This is 10,000 joules of energy used every second 24 hours a day, seven days a week, 365 days a year. This amount of power is equivalent to constantly running two clothes dryers, six blow dryers, 500 laptops, or 100 human metabolisms.

SOURCES: Murphy (2014); EIA (2015).

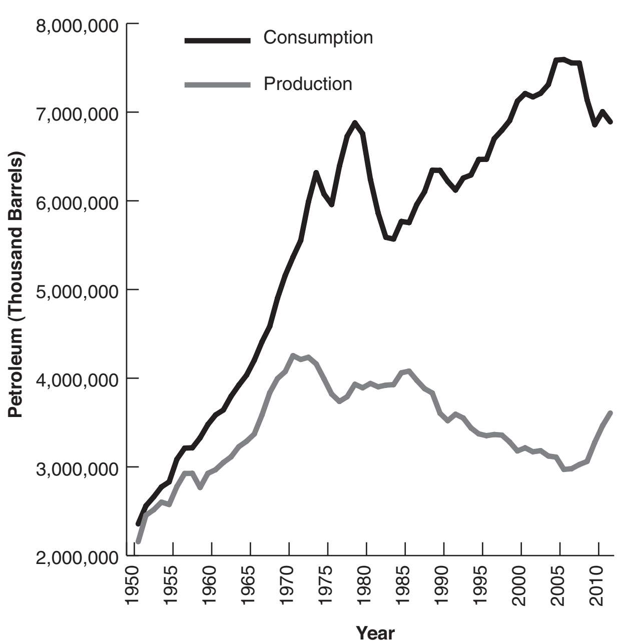


FIGURE 1.6 Comparison of US production and consumption of petroleum from 1950 to 2011. Beginning in the 1950s, the consumption of petroleum in the United States quickly began outpacing the production. This resulted in an increase in petroleum being imported from foreign sources (data from EIA, 2012).

Beginning around 1970, the consumption level is much higher than the production level. To meet the rising demand that the increased consumption level represents, the United States imports petroleum from foreign nations to fulfill the gap between production and consumption levels.

Over the last century, global production of fossil fuels has kept pace with the rising levels of consumption every year. However, keeping up with the projected growth in the future is likely to come at a significantly increased price. Fossil fuels are a finite resource and the extraction of these resources can vary leading to fluctuations in their costs. For instance, as sources of petroleum that are easier to extract are depleted, the new sources that come on line like tar sands and shale oil are likely to require more infrastructure or increased use of energy resources and result in generally higher costs for a barrel of oil. Eventually, this cost may become higher than most people are willing or able to handle. Chapter 2 will discuss how even though fossil fuels were created hundreds of millions of years ago, we will likely burn through these reserves in just a few hundred years. Once these resources are depleted, there is no way to speed up the natural process of creating fossil fuels.

To understand fossil fuels as a finite resource, it is important to consider an estimation of the remaining resources available on Earth using a term called **proved reserves**. A

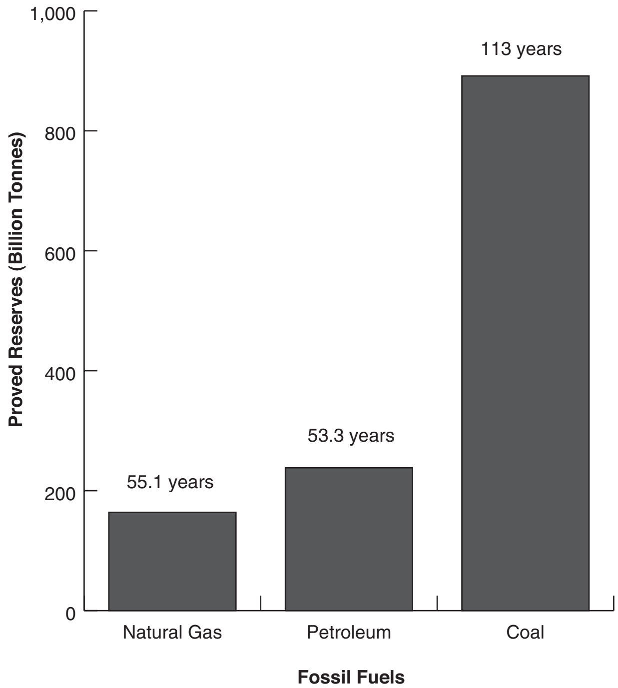


FIGURE 1.7 Global proved reserves for oil, natural gas, and coal, 2013. Reserve-to-production (R/P) values representing the number of years remaining for each fuel at current production levels are listed above each column. Estimates predict that globally coal will last the longest, but these values are likely to change as energy resources are consumed and new reserves are identified and accessed (data from British Petroleum, 2014).

proved reserve is the estimated quantity of a natural resource like a fossil fuel available for extraction on Earth using the technologies available today. These reserves estimate the total amount of a fossil fuel resource available for production and ultimately consumption. By dividing the proved reserve by our current production levels for that fossil fuel, the number of years remaining for a given fossil fuel at current production levels can be estimated, known as the **reserve-to-production ratio** (R/P). Figure 1.7 shows the global proved reserves and R/P values for coal, natural gas, and petroleum as of 2013. The R/P value for both natural gas and petroleum indicate that these resources will be significantly depleted within the next 50 years, a period likely within the lifetimes of many people today. Coal is estimated to outlast both natural gas and petroleum; however, with current energy infrastructure, there may be an increased use of coal as natural gas and petroleum are depleted. This option will ultimately decrease the number of years of availability remaining for coal and could have vast environmental consequences.

As these fossil fuels become depleted over the next few decades, the world will likely see a drastic increase in cost associated with a decline in production levels, a fluctuation we see even today for petroleum. The limited availability and less competitive pricing for some of the world's most important commodities will undoubtedly have a huge impact on society in terms of both security and economics. The best way to manage the impact of these changes is to diversify worldwide energy production and consumption by developing alternative and renewable forms of energy.

The Future of Electricity and Transportation

The diversification of energy utilization from fossil fuels to renewable energy technologies requires understanding how we use each of these fossil fuels within modern society today. Figure 1.8 graphs the consumption of various forms of energy based on different sectors within society. Through this graph, it is evident that coal, natural gas, nuclear, and renewable sources are more commonly used for residential, commercial, industrial, and electrical applications, while petroleum dominates the transportation sector. One of the main reasons why these industries require different fossil fuel resources is explained through two related terms: energy and power. Earlier in the chapter, the five types of energy and the definition of energy as being the capacity to do work were discussed. It was explained that energy cannot be created nor destroyed but only transferred from one form to another. This transformation is what ultimately differentiates energy and **power** because this transformation allows energy to take on a form that can be stored and used when needed. Power is slightly different. Power uses energy but has an associated time component. Power is energy divided by time and is usually expressed in terms of watts where a watt is equivalent to the transfer of 1 joule of energy per second. While oil is an energy source, electricity is a power source. A key difference between these two is that an energy source such as oil can typically be stored, while a power source such as electricity is used as it is generated. This is an important concept when considering that in the United States and most nations around the world, daily infrastructure relies on the availability of both a stored energy source and a power source.

Today, burning coal and natural gas are the two most common methods used to produce power. The heat from burning these fossil fuels is used to create steam. The pressure of the steam will turn a turbine providing energy to a generator that then generates electricity. **Electricity** is the flow of negatively charged electrons from one atom to another usually induced by a magnetic field. In an electrical generator, the turbines move magnets and a good electron conductor like copper together to create an electrical current. This current of electrons runs in a circuit, and as long as nothing blocks this circuit, the electrical energy continues to flow. However, if the circuit is broken, then the flow of electrons stops and so does the electrical energy. One can envision this by thinking about a wall socket for an electrical device like a light with a plug. When the plug is put into the wall socket, the two prongs create a circuit and the light will turn on. But, as soon as the light is unplugged from the

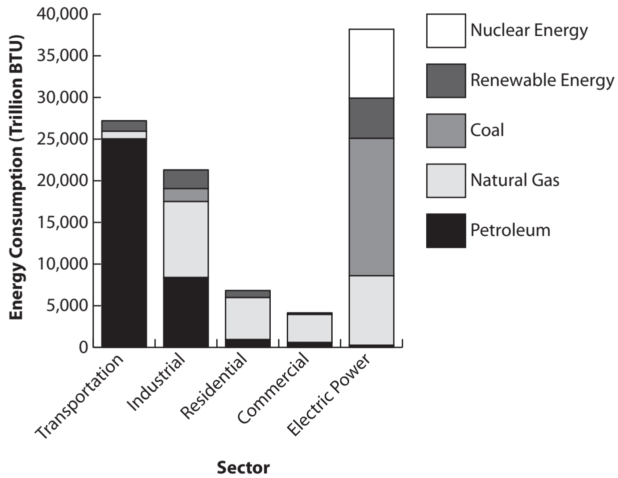


FIGURE 1.8 US primary energy consumption by source and sector, 2013. The transportation sector relies heavily on the availability of petroleum. The industrial sector also uses petroleum and consumes significant quantities of natural gas. Natural gas is an important component of both commercial and residential sectors as well. Electric power is the largest consumer of energy derived almost entirely from coal, natural gas, renewable resources, and nuclear energy (data from EIA, 2014b).

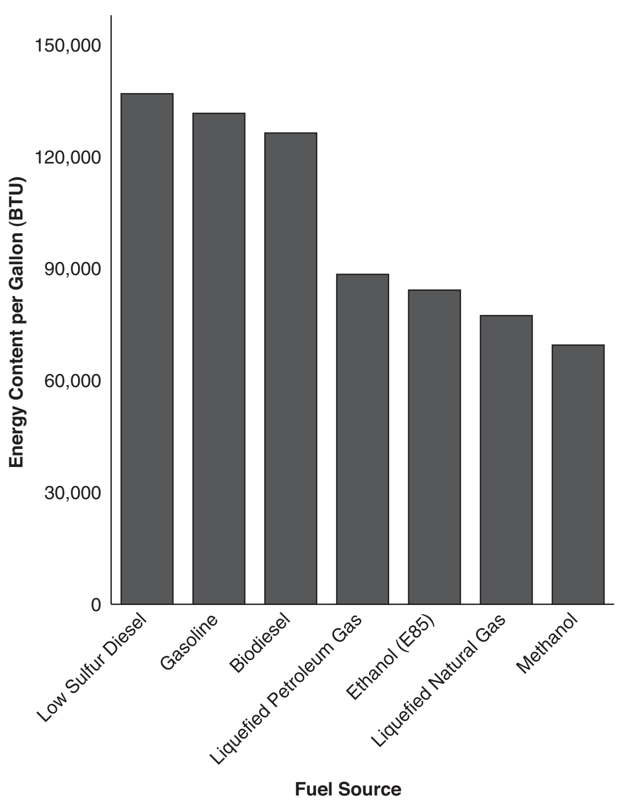


FIGURE 1.9 Comparison of the energy content contained within various types of fuels. Liquid hydrocarbon-based fuels have the highest energy contents per gallon when compared to alternative liquid fuels like methanol and ethanol (data from US Department of Energy, 2011).

wall, the light goes out because the circuit has been broken and the electrons are no longer flowing.

Electricity is one of the most highly used sources of energy in the world and is produced primarily from coal and natural gas. According to the International Energy Agency, in 2012 40.4% of worldwide electricity was produced from coal, 22.5% from natural gas, 16.2% from hydropower, 10.9% from nuclear power, and only 10% from all other sources including petroleum (IEA, 2014). Coal and natural gas are ideal sources for steam generation because they contain a lot of energy that can be burned at high temperatures to create steam. However, both coal and natural gas are finite resources as mentioned earlier, and they are responsible for environmental damage in the form of releasing harmful atmospheric gases. The value of electricity to society and the desire to lower the environmental impact of electricity usage has led to the development of other ways to generate electricity including many renewable sources. Both nuclear energy and hydropower have been used for the production of electricity for decades, while newer electricity sources such as wind and solar power technologies are continuing to advance and grow in popularity around the world. These renewable energy sources will be discussed in Chapter 4.

While the residential, commercial, and industrial sectors rely heavily on coal and natural gas for power, the transportation sector relies almost completely on the availability of the third fossil fuel, petroleum. Petroleum is naturally occurring crude oil derived from decayed oceanic algae and cyanobacteria, and is the precursor to many items common in everyday use including gasoline, plastics, and motor oil. The chemical and biochemical properties of petroleum will be further discussed in Chapter 2. However, there are two main reasons why petroleum has become the fossil fuel used for the transportation sector. First, petroleum and petroleum products have very high-energy contents. In figure 1.9, one can see that, when compared to other products being developed as fuel alternatives including ethanol and liquefied natural gas, the petroleum products of gasoline and diesel have much higher energy densities. Secondly, the transportation sector requires an energy source that is transportable. Transportation relies on the ability of vehicles to move from one location to another, making the use of power generation from coal or natural gas more difficult to take advantage of in a vehicle. However, as many petroleum products such as gasoline are liquids, they can be pumped into a vehicle and stored in the gas tank until needed by the engine. These characteristics of petroleum make it absolutely ideal for use in the transportation sector and extremely difficult to replace with other alternative energy sources.

The Future of Petroleum

Petroleum is an extremely valuable commodity in modern society, a commodity that is often taken for granted. This is largely due to the value it has in the transportation sector and its function in allowing for increases in the number of personal vehicles on the road, distances traveled by airplanes, and the constant availability of basic goods like food and household products. There is no better place to see the impacts of petroleum than in the United States where people drive personal vehicles long distances regularly, rarely use public transportation, and stock fresh produce in grocery stores even when out of season, thanks to the ability to transport food all over the world by trucks and airplanes. Over the past century, the reliance on petroleum in the United States has resulted in massive increases in its consumption. In 1949, the United States consumed about 5.7 million barrels of petroleum a day, but in 2013, the country consumed about 19 million barrels of petroleum every day, an increase of 235% (EIA, 2014a). Unfortunately, these increases in consumption have not completely matched with increases in domestic production levels; however, recent years have shown an increase in domestic production largely due to the development of infrastructure for the extraction of shale oil. But shale oil is generally more expensive than the conventional sources of foreign oil that have been imported for many years.

Figure 1.10 shows the production of petroleum in the United States since 1860. Notice that in the 1970s the level of petroleum production in the United States was at its highest. This time period is called **peak oil**. Peak oil is the point at which a country or the world is producing the maximum number of barrels of oil per day possible. While this appears to have happened in the 1970s for the United States, the world's peak oil point was likely reached sometime around 2007 (Nashawi et al., 2010; EIA, 2014a). The importance of peak oil is that it is the maximum; there will no longer be increases in production levels and this usually indicates that production levels will begin to decrease after this point. Unfortunately, looking back at figure 1.6 one will also see that, while the United States has surpassed peak oil, consumption levels have certainly not peaked. Recently the United States has seen an increase in oil production using hydraulic fracturing or fracking. This increase in oil production was brought about not because new oil fields were discovered, but rather because the price of oil rose to a level sufficient to support oil production using fracking technologies. Although this increase has been dramatic over the last five years with almost 3 million barrels of oil per day added to US production levels, even this new expensive oil production cannot get us back to a new peak oil level or even keep pace with the world's energy consumption increase (British Petroleum, 2014).

Consumption of petroleum in the United States declined significantly during the economic downturn of 2008, but this decline has reversed as the economy has improved. Today even with the increase in fracking-based oil production, the United States still has a large gap between the amount of production within the country and our consumption levels. In order to fill in this gap, the United States continues to import significant amounts of oil, about 7.4 million barrels per day or 40% of the consumption levels in 2012, the lowest average since 1991 (EIA, 2014a).

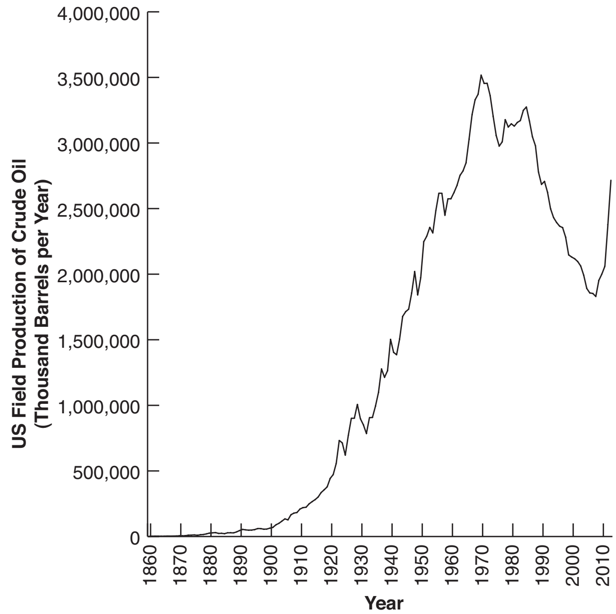


FIGURE 1.10 US annual production of crude oil between 1860 and 2013. Graph shows that peak oil production occurred in the 1970s. Recent years have shown an increase in crude oil production likely due to the development of shale oil extraction techniques (data from EIA, 2014c).

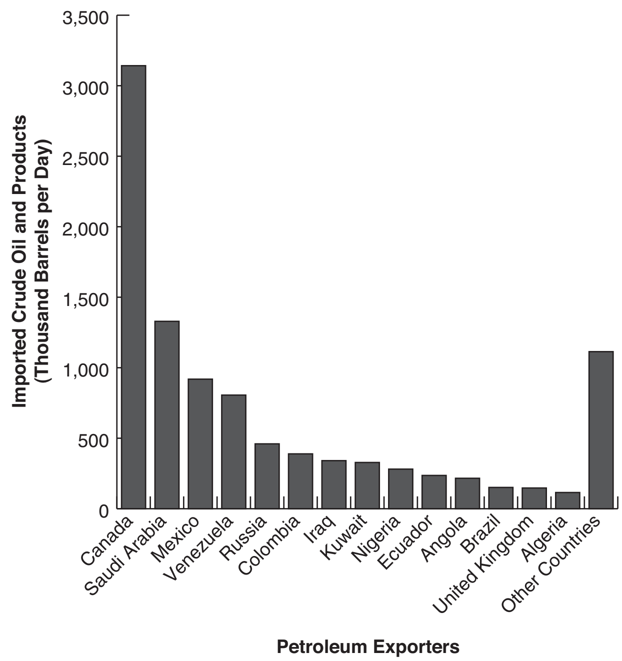


FIGURE 1.11 Annual US petroleum imports by country of origin for 2013. Canada is the most important source of foreign oil imported into the United States followed by Saudi Arabia (source: EIA, 2013).

Figure 1.11 shows that Canada is the major source of imported oil in the United States followed by Saudi Arabia, Mexico, and Venezuela. The importation of such a significant amount of foreign oil opens the door to two major problems: supply and energy security. Since the United

States is clearly dependent on a steady flow of oil from foreign locations, there is a significant chance that those supply lines could be disrupted in times of foreign instability. An example of this situation is seen when oil prices rise due to unrest in the Middle East, Africa, or other oil-exporting countries. The second problem is energy security. The economy of the United States and the world depends on the availability of fossil fuel resources including petroleum. If the supply of petroleum is disrupted, or the price of petroleum rises dramatically, then national economies suffer and this impacts national security.

While petroleum plays a critical role in the economy and societies of the world, it is also a fossil fuel that similar to coal and natural gas has a negative impact on the environment. When petroleum is used either in the engine of a car or in industrial processes, it releases harmful environmental pollutants including greenhouse gases. Chapter 3 will discuss how these gases are leading to global warming and climate change.

Unlike coal and natural gas used for electricity production, the opportunities to develop renewable energy sources to replace petroleum and lower its negative impacts on society are few. However, scientists are working on technologies that can produce fuels that have high energy densities, a low environmental impact, and the capacity to be easily transported like petroleum. One of these technologies is biofuel. Biofuels are a source of chemical energy derived from the sun and sequestered in plants or algae. Plants and algae can be used to produce a number of different biofuels including bioethanol and biodiesel that may represent alternatives to liquid petroleum products.

Plants and algae are capable of absorbing massive amounts of carbon dioxide and utilize sunlight to efficiently convert this carbon dioxide into stored chemical energy in a process called photosynthesis. Since all fossil fuels are originally derived from decaying plants and algae, it seems natural to look at these organisms as a replacement for crucial fossil fuel resources.

The next several chapters will cover more about the history and importance of fossil fuels, particularly petroleum to society, and the renewable energy technologies that are being developed to help replace these fossil fuels. These chapters will provide the background needed to understand the latter parts of this book focused on the various bioenergy technologies, their development, and their potential impact on the energy market and the environment. By the end of this book, one will understand the importance of developing alternative energy technologies and the value that bioenergy could have in modern society.

STUDY QUESTIONS

1. Explain the definition of energy. What types of energy exist? Do we create energy?
2. Is petroleum considered a primary energy source? Why or why not? What are the four primary energy sources on Earth?
3. Why will the energy market continue to expand over the next several decades?
4. If GDP per capita and primary energy consumption per capita are linked, then what are the implications of a rising standard of living in many countries around the world?
5. What makes fossil fuels such a valuable commodity on the global market for energy?
6. How have US energy consumption and production changed in the last 60 years? What happens when the US consumption falls below its production level? Who do we rely on to fill these gaps?
7. How do we calculate how much of a given fossil fuel is remaining? How many years do we have remaining for coal, natural gas, and petroleum?
8. Why are different energy resources used in different sectors?
9. What is peak oil and what does this tell us about the future of petroleum?

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