7

Sustaining Our Energy Resources

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Learning Outcomes

After reading this chapter, you should be able to

- Define basic energy concepts.
- Describe current energy sources and uses and how that might change in the future.
- Explain how fossil fuels are formed.
- Analyze the impact and future of coal.
- Analyze the impact and future of oil.
- Analyze the impact and future of natural gas.
- Analyze the impact and future of nuclear energy.
- Describe the opportunities and challenges of the energy transition.
- Identify examples of energy efficiency and conservation.
- Analyze the impact and future of solar energy.
- Analyze the impact and future of wind energy.
- Analyze the impact and future of bioenergy.
- Analyze the impact and future of hydroelectric energy, geothermal energy, and ocean energy.
- Describe what goes into the true cost of energy and what policies might be enacted to encourage renewable energy.

Much like water, energy is a resource we use every day without ever really giving much thought to where it comes from or what the consequences of its use are for the planet. Take a casual inventory of your home or apartment and consider all the devices and consumer products that are currently plugged into a wall outlet. Televisions, computers, refrigerators, microwave ovens, toasters, cell phone chargers, and other consumer products are constant users of energy, day in and day out.

Now consider that your household is only 1 of about 130 million households in the United States, and only 1 of about 1.6 *billion* households worldwide. Now add to this all the energy that you and others use *outside* of your home—for transportation, while at work, and in other settings like schools and hospitals. Finally, add to that all the energy used worldwide by commercial businesses and industries to produce, package, transport, and deliver all the items you consume every day—your food, water, clothing, and other consumer products.

The sheer scale of global energy use would seem to make its measurement almost impossible, and yet every year experts at the U.S. Energy Information Administration (EIA) do just that. The EIA estimates that global energy consumption in 2018 was almost 600 quadrillion British thermal units (Btu). This compares with global energy use of about 360 quadrillion Btu (quads) in 1990, 400 quads in 2000, and 500 quads in 2010. Furthermore, the EIA (2018) projects global energy use to increase to 739 quads by 2040.

It's difficult to attach a human scale to these numbers. What is a Btu, and what does it mean to use 600 quadrillion (600 with 15 zeros added) of them? Technically, a Btu is the amount of heat energy required to raise the temperature of 1 pound of water by 1 degree Fahrenheit. Six hundred quadrillion Btu is roughly equivalent to the amount of energy in 27 billion metric tons of coal or 102 billion barrels of oil. In reality, even these measures are difficult to comprehend in the abstract. What we can say, however, is that global energy use is massive and growing.

Our global energy use is also highly destructive to the environment. We currently depend to a great extent on coal, oil, and natural gas to meet our energy needs. These resources are finite, and the extraction and use of these fuels contributes to water pollution, air pollution, ecosystem destruction, and global climate change, among other environmental impacts. Environmental scientists are more convinced than ever that we need to move away from what are known as *nonrenewable* sources of energy to *renewable* sources, including solar and wind. Such an energy transition is already under way. The question is whether it can happen fast enough to avoid the worst of the environmental impacts described.

7.1 Our Current Energy System

While we may hear the term *energy* used frequently in the news, in political debates, and in discussions of environmental issues, we seldom take the time to ask what that term means. Recall from Chapter 2 that *energy* is the capacity to do work. Sunlight (solar energy) enables plants to photosynthesize and grow. Humans and other animals eat plants to obtain the energy stored there in order to build our bodies, move, and do other forms of work. And we use energy stored in coal, oil, and other fuels to heat our homes, power our devices, and move our vehicles.

This section is designed to provide you with an overview of how our energy system works. Understanding the forms energy takes in our everyday lives is important as you consider how we might transition to a new energy economy.

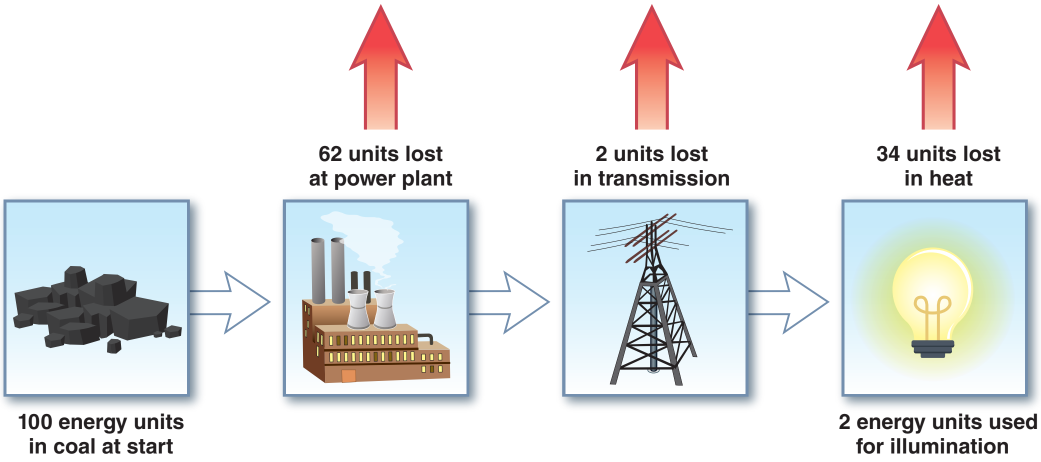
Key Concepts

We can classify energy a number of different ways. **Primary energy** is the energy stored in natural resources such as coal and wind. Primary energy typically must be converted into a form more useful to us—a process known as **energy conversion**. For example, the primary energy contained in a ton of coal is used in an electric power plant to boil water and produce steam, which spins a turbine that produces electricity. In this case, the electricity produced is known as **secondary energy**—a form of energy that is more convenient for us to use. Likewise, the energy contained in a gallon of gasoline can be converted to kinetic energy in an automobile. We ultimately use energy to achieve an "end use" such as lighting for our homes or movement of our cars.

Recall from Chapter 2 that the second law of thermodynamics holds that no energy conversion is 100% efficient and that in every energy transformation, some energy is lost as heat. For example, when coal is burned in a power plant to produce electricity, roughly 70% of the chemical energy available in that coal is lost to heat, while only 30% is converted into an electric current. Likewise, when that electricity reaches your home or apartment and is transformed into light energy in an incandescent lightbulb, as much as 95% of the electric current is converted to heat, while only 5% or less is used to produce visible light. The term **energy conversion efficiency** describes the percentage of primary energy converted to secondary form—30% in the case of coal in an electric power plant. The term **energy end-use efficiency** describes the percentage of primary energy used in its final destination. In the case of burning coal to produce electricity to power an incandescent lightbulb, the energy end-use efficiency can be as low as 1% to 2% overall (see Figure 7.1).

Figure 7.1: Energy conversion

Only 2% of the energy available in coal is used to power an incandescent lightbulb because so much energy is lost in the process.



Primary energy sources can be further broken down into categories of nonrenewable or renewable. **Nonrenewable energy** sources are just what they sound like; energy sources that, once consumed, are no longer available for future use. Nonrenewable energy sources include the three main types of fossil fuels—coal, oil, and natural gas—as well as nuclear. As we'll discuss, fossil fuels were formed by geological processes that took millions of years, so once we use them, they are essentially gone forever. Nuclear energy is produced using uranium, another resource that exists in limited supply. Compare that with **renewable energy** sources like solar and wind. Using sunlight to generate electricity through a solar panel, or wind to generate electricity through a spinning turbine, does not deplete those resources. However, we can only make use of these renewable energy sources when they are available. For this reason, energy experts often refer to nonrenewable energy sources as being "stock limited" and renewable energy sources like solar and wind as being "flow limited."

Global Energy Consumption

For most of human history, the primary sources of energy were sunlight, muscle power, and firewood. The ability to do work was limited by the number of hands available. With the agricultural revolution and the domestication of animals, activities like plowing and pulling wagons could be accomplished with animal power. Technological innovations gradually introduced ways to use energy from moving water (waterwheels) or wind (windmills) to mill grain or pump water. And throughout most of human history, we have burned firewood, crop residues, and dried animal dung for cooking, heating, and lighting.

The ways in which we use energy, as well as the types and quantities of energy used, began to change dramatically in the second half of the 18th century. The single most important reason for this change was the development of the steam engine. Steam engines could be used to move ships, trains, farm equipment, and factory machinery. Initially, steam engines were powered by firewood, but in major areas of demand this resulted in overcutting of forests and eventually wood shortages. In response, coal began to be exploited as an energy source, and by the late 19th century it became the dominant form of energy worldwide.

Coal remained the number one source of energy in the world until around 1950, when oil took over the number one spot. Oil was easier to extract and was much easier and cleaner to use, so many homes and businesses began to prefer oil to coal. Nevertheless, coal remains to this day the second most important global source of energy, and it is particularly important for industrial uses and electric power production. Since the late 20th century, natural gas has grown in importance and is projected to surpass coal in the near future to become the second most important energy source. Natural gas is a cleaner burning fuel than coal and is relatively easier to extract, transport, and utilize. As a result, many electric power companies have been shifting from coal to natural gas for electricity production. Renewable energy sources like hydropower, geothermal energy, solar energy, wind power, and biomass energy are currently the fourth most important form of energy worldwide, although these energy sources are also witnessing the fastest growth. Finally, nuclear energy—used almost exclusively for electric power production—is the fifth most important form of energy worldwide.

In addition to the EIA's report, BP (2019) also publishes an annual *Statistical Review of World Energy*. BP reports global energy production and consumption in millions of tonnes of oil equivalent (Mtoe), rather than in quads. BP estimates global energy consumption in 2017 was 13,511 Mtoe, up from 11,588 Mtoe 10 years earlier. Of that 13,511 Mtoe of consumption, nonrenewable fossil fuels are currently meeting about 85% of global energy demand. At the same time, the nonrenewable share of global energy supply is slowly declining over time. Oil, coal, and natural gas combined for 95% of global commercial energy demand in the late 1960s, 90% in the late 1980s, and 88% in 2008. Recent declines in the share of global energy from nonrenewable sources, while small, can be entirely accounted for by increases in the use of renewable energy sources like wind and solar.

If we look at global energy use on an individual, or per capita, basis, we can observe large differences in both the amounts and types of energy used in different countries around the world. The World Bank reports per capita energy use by country in kilograms of oil equivalent (kgoe). For 2013, the last year the World Bank published estimates, per capita energy consumption varied from as low as 215 kgoe per person per year in Bangladesh to as much as 7,202 kgoe per capita in Canada. Developing countries like Ghana, Haiti, and the Philippines had per capita energy consumption rates from 343 to 457 kgoe, while energy use in more developed countries like France, Germany, and Japan averaged around 3,700 kgoe per person per year. And whereas China is now the world's largest consumer of energy, with the United States second, per capita rates of energy use in China (2,226 kgoe) are only one third of those in the United States (6,916 kgoe; World Bank, 2014).

Energy Sources and Uses

Unlike our use of drinking water, seafood, fruits, vegetables, or meat discussed in recent chapters, we don't really "demand" energy resources directly. We do not wake up in the morning and decide that we really need a ton of coal or pick up a barrel of oil on the way home from work. Instead, what we want from energy resources are the services they provide—heat, mobility, and electricity for lighting and powering our devices. These are known as energy end uses. Broadly speaking, we can break our nation's energy consumption into four major end-use categories: transportation, industrial uses, residential uses, and commercial uses. We can also consider electric power generation as a major end use for energy resources, although in this case it actually represents a transformation of energy from one form to another.

It turns out that certain types of energy resources are better adapted or better matched to specific energy end uses than others. For example, coal may be the second most important energy resource worldwide, but it makes essentially no contribution to meeting our transportation needs. Likewise, oil or petroleum may be the single most important energy source globally, but—at least, in the United States—it makes almost no contribution to electric power generation. Understanding the connection between energy sources and uses is important if we are to avoid misunderstandings about appropriate energy policy. During the oil crises of the 1970s, when a global oil embargo severely reduced the supply of oil to the United States, the nuclear power industry launched an advertising campaign arguing for increased nuclear power production as a way to reduce dependence on imported oil. However, since our transportation system at the time, and even today, depended almost entirely on oil rather than electricity, increased nuclear power production would have had essentially no impact on oil import levels.

Perhaps one of the best ways to understand energy sources and uses, as well as levels of overall energy use in our economy, is to examine what's known as an *energy flow chart*. In the United States the Lawrence Livermore National Laboratory (LLNL) produces the most detailed and informative energy flow charts. For our purposes, we will discuss the chart the LLNL published in 2018, which you can view at the following link: https://flowcharts.llnl.gov/content/assets/docs/2018_United-States_Energy.pdf. A more recent energy flow chart may be available at https://flowcharts.llnl.gov.

The left side of the LLNL energy flow chart shows the major energy sources used in the United States in 2018, such as petroleum, natural gas, and hydroelectric power. The number below each listed energy source represents the total amount consumed, measured in quads, and corresponds to the width of the line flowing out from each box to the right. For example, the light blue natural gas line is more than twice as wide as the black coal line because natural gas was used more than twice as much as coal was. Added together, all these energy sources totaled 101.2 quads of energy consumption in the United States, or about one sixth (17%) of global energy consumption for that year.

The boxes those lines flow toward indicate how certain energy sources are matched with specific energy end uses. For example, in the United States petroleum is predominantly used for industry and transportation, and the width of the dark green lines tell us that petroleum is first and foremost a source of energy for transportation. Likewise, coal, nuclear, hydro, and wind are almost entirely utilized to produce electricity. That electricity is then utilized in the residential, commercial, and industrial sectors, with virtually no electricity going to the transportation sector. Natural gas appears to be a more versatile energy source, with significant uses in electric power production, industrial purposes, residential home heating, and commercial applications.

The LLNL energy flow chart shows us that not all energy sources are created equal. As we consider our energy future, we must recognize that we cannot simply stop using petroleum overnight and power our trucks and cars with coal, wind, or nuclear power. We *could* do this over time if we changed the way we build cars and trucks and shift to electric engines, but such a transition takes time.

The LLNL energy flow chart also clarifies just how much energy is lost during energy conversions, which is referred to as *rejected energy* (light gray lines and boxes). For example, of the 38.2 quads of energy that are utilized to generate electricity, fully 25.3 quads (66.2%) are lost as rejected energy, mainly in the form of heat. Likewise, of the 28.3 quads of energy from petroleum and small amounts of ethanol and natural gas used in the transportation sector, 22.4 quads (79%) are lost as rejected energy. Overall, 68.5 of the 101.2 quads (67.7%) of energy used in the United States in 2018 were lost as rejected energy, with only 32.7 quads delivering actual energy services of mobility, heat, lighting and other applications.

There is growing consensus that the United States and the rest of the world need to undergo a rapid **energy transition**, moving away from an overwhelming reliance on nonrenewable fossil fuels to a world powered primarily by cleaner renewable energy resources. Such an energy transition is already under way, and we will discuss the opportunities and challenges later in the chapter. At this point, simply remember that planning this energy transition involves careful consideration of available energy sources and uses. For example, 95% of the 28.3 quads of energy currently used in the U.S. transportation sector comes from either petroleum or natural gas. To successfully and quickly transition away from these nonrenewable fossil fuels, what are our options?

One possible approach is to shift to liquid fuels derived from biomass, such as ethanol from corn. Biofuels like ethanol currently meet about 10% of transportation energy needs in the United States, so this is something of a proven technology. However, as we'll discuss, increasing corn production to produce more biofuels generates a different set of environmental impacts that may actually be worse than continuing to rely on petroleum.

A second option for transitioning away from fossil fuels in the transportation sector is to move toward electric cars and trucks. When in use, electric vehicles (EVs) emit no air pollution or greenhouse gas emissions, and so they would seem to be an ideal way to transition from nonrenewable fossil fuels to a clean energy future. However, the actual impact of a transition to an EV fleet will depend to a large extent on how we generate the electricity used to charge these vehicles. Considering that we currently depend on coal for 34% of electric power production in the United States and natural gas for another 26% of our electricity, transitioning to EVs would have only a limited impact on efforts to reduce our dependence on nonrenewable fossil fuels and reduce greenhouse gas emissions. Furthermore, shifting from an oil-based transportation system to one that is powered by electricity would require significant investments in new infrastructure that would take time to put in place.

Achieving a clean energy transition in the transportation sector thus depends on accomplishing two large-scale changes in terms of energy sources and uses. First, we need to continue to increase the percentage of electric power produced by clean energy sources like solar and wind. Second, we need to undertake a fundamental shift away from a vehicle fleet built on the internal combustion engine to one powered by electric motors. The first of these changes appears to be well under way. The percentage of U.S. electric power production coming from solar, wind, hydro and other renewable energy sources doubled from 9% in 2008 to 18% in 2018 (EIA, n.d.). In terms of the second change—a large-scale shift from internal combustion to EVs—there is disagreement among energy experts as to how or when this will happen. Some experts predict that we are on the verge of a large-scale changeover and that rapid growth in demand for EVs in places like China will prompt U.S. automakers to speed up their production and distribution of these vehicles in the United States as well. However, other experts are more skeptical and point to infrastructure challenges such as a lack of charging facilities as a key barrier to rapid adoption of EVs.

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Transitioning fully to electric cars would take time, since infrastructure is still a challenge. The overall environmental impact would ultimately depend on how we generate the electricity used to charge these vehicles.

The important point to make at this stage is to reemphasize that energy sources and uses are not easily interchangeable. Earlier energy transitions—from wood to coal in the 18th and 19th centuries and from coal to oil in the 20th century—involved numerous changes in the ways we produced and utilized energy. Likewise, transitioning away from nonrenewable coal, oil, and natural gas to renewable energy sources will also require changes in the ways we convert, store, and utilize that energy. An important factor in determining how fast such an energy transition can occur will be energy policy and how energy prices are determined and set. We'll consider those factors in more detail in section 7.13. The next section takes a closer look at the fossil fuels that currently dominate our energy economy, including an examination of their origin, extraction, end use, environmental impacts, and future potential.

7.2 The Cost of Fossil Fuels

Coal, oil, and natural gas are known as **fossil fuels** because they were formed from the remains of organisms that lived 100 million to 500 million years ago. During that period, large areas of the planet were covered in freshwater swamps and shallow oceans that supported an abundance of plant life and phytoplankton. This plant life and phytoplankton utilized solar energy through photosynthesis to convert carbon dioxide and water into organic carbons.

Because these environments were so productive, organic material from dead plants, phytoplankton, and other dead organisms accumulated more quickly than they could be broken down by decomposers. Thick layers of organic material accumulated at the bottom of these bodies of water and built up over time. Gradually, this organic material was covered by layers of sediment, further impeding any decomposition. Over millions of years, as sediment layers covering this organic material became thicker and thicker, a tremendous amount of weight, pressure, and heat were applied, producing coal, oil, or natural gas, depending on conditions and the organic source material. In a somewhat ironic twist, you could say that fossil fuels are an ancient form of solar energy, since they originated from plant material and living organisms formed through photosynthesis.

Even though there are many different terms and categories used to classify fossil fuel deposits, geologists focus on two primary breakdowns. The first has to do with how concentrated and accessible a fossil fuel deposit is. Geologists use the concept of a *resource pyramid* to express this. Highly concentrated and easily accessible fossil fuels make up the top of the pyramid. These are the fuels that energy companies exploit first because they have the lowest production costs, such as oil deposits that gush from the ground or high-quality coal deposits close to the surface. When these deposits have been exhausted—as most have been—energy companies have to move down the resource pyramid to deposits that are more numerous but also more difficult to develop. These deposits are less concentrated, are more remote and harder to access, and require more effort to develop, such as offshore oil or deep coal deposits. Further yet down the resource pyramid are fossil fuel deposits that are of such low concentrations and/or in such difficult-to-reach locations that it would not make any economic sense to extract them unless energy prices were to go much higher.

This is also why geologists and energy experts point to the fact that we won't really run out of fossil fuels, since there will always be some deposits that are simply not worth the effort to extract. It also highlights a concept known as **energy return on investment (EROI)**, or the amount of useful energy extracted from a resource divided by the amount of energy it took to produce that energy. Energy deposits at the top of the resource pyramid have a high EROI since they produce a lot more energy than the energy needed to extract them. Further down the resource pyramid, the EROI number declines, until we reach an EROI of 1:1, where the amount of energy extracted is equal to the amount of energy used to extract it. Such a situation makes little sense, and so energy companies would probably abandon a deposit long before that point. In the United States the EROI for oil and gas production has declined from 30:1 in the 1960s to about 10:1 today (Guilford, Hall, O'Connor, & Cleveland, 2011).

The second category of difference for classifying fossil fuels (especially oil and gas) involves whether a particular deposit is conventional or unconventional. Historically, we have exploited **conventional deposits** of oil and gas found in porous rock formations. Traditional drilling techniques are used to bring oil and gas from these deposits to the surface. However, geologists have long been aware of oil and gas found in **unconventional deposits**, such as oil-soaked sands or shale formations that have trapped gas. As we'll discuss, these unconventional deposits are more difficult to exploit, and extraction typically results in more serious environmental impacts. But because most of the productive conventional deposits have already been heavily exploited, unconventional deposits are now the focus of much more attention than they were in the past. The move from conventional to unconventional deposits also helps explain the declining EROI figure for oil and gas production, since the latter require more energy and effort to exploit.

Another concept common to the use of fossil fuels is that of external costs or externalities. An *external cost* is a cost associated with the use of a product that is not reflected in the price we actually pay for that product. For example, when coal is mined and burned to produce electricity, it can have a number of environmental impacts. Coal mining can harm water quality, and coal burning can create air pollution. If poor water quality or air pollution make someone sick, the cost of treating that illness is usually not factored into the price for that coal or the electricity it was used to produce. Those health care costs are external costs, and they represent a hidden cost to the use of fossil fuel energy resources because they mask or hide the true costs associated with actually using that resource.

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Conventional deposits can be more easily accessed and brought to the surface using conventional drilling techniques, like those pictured. Unconventional deposits require more energy to extract and have lower EROI.

The next sections will take a closer look at each of the three main fossil fuels and consider issues related to their production, use, environmental impacts, and future.

7.3 Coal

Most of the coal we use today originates from swampy forests of 300 million to 400 million years ago. Over millions of years vegetation in these swamps fell to the ground and accumulated in layers faster than it could decompose. Swampy conditions limited oxygen supply and resulted in partial, anaerobic decomposition, producing a material known as *peat*. As peat was buried under more and more layers of sediment, it pressed out most of the water and

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Coal seams like this one are the result of swampy vegetation that was buried under sediment and then transformed by pressure and the Earth's heat.

squeezed the organic material more tightly together. This pressure combined with heat from the Earth's interior to produce layers of coal, or **coal seams**.

Coal production in the United States has an estimated EROI of roughly 60:1, whereas in China this figure is closer to 25:1. This means that from 25 to 60 useful units of coal energy are extracted for every 1 unit of energy used in its extraction. This relatively high EROI (compared to oil and gas) reflects coal's abundance and ease of extraction. Coal is the most abundant of the fossil fuels, with global *proven reserves* estimated at about 1.1 trillion metric tons. **Proven reserves** of a fossil fuel are defined as the quantities of that energy source that can be extracted from *known deposits*, using *current technology*, at *current prices*.

When thinking about the future of fossil fuels, it's useful to consider the **reserves-to-production (R/P) ratio** (the proven reserves divided by annual consumption), which indicates how long a resource will last. With 1.1 trillion metric tons of proven coal reserves and global coal consumption at 7.8 billion metric tons a year, the R/P ratio is about 140, meaning that at current rates of consumption, we have at least 140 years of coal remaining. The R/P ratio in the United States is even better: With about 240 billion metric tons of proven reserves and annual consumption of about 1 billion metric tons, the United States has at least 240 years of coal remaining. However, burning all this coal using current technology would certainly doom the planet to catastrophic climate change. So unless another way can be found to utilize coal, this relatively high R/P ratio doesn't actually mean much.

Extraction

Coal is removed from the ground or mined in one of two ways. **Underground mining**, or **subsurface mining**, involves digging tunnels or shafts into the ground to reach coal seams that are deeper than 60 meters (200 feet). **Surface mining**, or **strip mining**, involves using giant earth-moving machines to scrape away vegetation, topsoil, and rock to reveal a shallower coal seam.

One form of strip mining, known as **mountaintop removal mining**, is used widely in the Appalachian region of Kentucky and West Virginia. In this approach, the entire top portion of a mountain is removed to expose the coal underneath, and the material (referred to as *overburden*) is dumped into surrounding valleys. Mountaintop removal mining is highly destructive to surrounding ecosystems, and the practice has been blamed for severely contaminating groundwater and causing downstream flooding.

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During the process of mountaintop removal mining, large overburden machines are used to transfer and dump excess material.

Once coal is mined it is used primarily for electric power production. Globally, around 40% of all electric power production comes from burning coal, whereas in China and India (the world's number one and number three top coal consumers), that figure is 65% and 62%, respectively. In the United States (the number two coal consumer), about one third of our electric power production comes from burning coal. In addition, well over 90% of the coal consumed in the United States is used to produce electricity, with small amounts used in steel production and for other industrial purposes.

Impact and Future

Beyond the negative environmental impacts associated with coal mining, especially mountaintop removal mining, burning coal also results in a number of other serious environmental problems. Coal combustion is a major contributor to smog formation and increased particulate levels in the atmosphere, both of which have negative health impacts and are associated with respiratory diseases and reduced life spans. Coal burning releases mercury, arsenic, lead, and other toxins that can impact human health and wildlife. Finally, as a major source of CO_2 emissions, coal burning can be linked with the impacts of global climate change, including changing weather patterns, increases in natural disasters, acidification of the oceans, and a variety of other effects associated with a warming world. Overall, we can say that coal extraction and use impose significant external costs—in terms of health impacts, water and air pollution, ecosystem destruction, and climate change—on society; costs that are not always factored into the price we pay for the electricity produced by coal.

Coal consumption peaked in the United States around 2007 and has been in sharp decline since. U.S. coal consumption in 2018 fell to its lowest level since 1979. While some politicians and coal industry executives have blamed this decline on a regulatory "war on coal," the actual reason for declining coal use lies with the energy market. Specifically, the past 10 to 15 years have seen sharp increases in the production and supply of natural gas and declining prices for this fuel. Cheaper and cleaner natural gas has been displacing coal in many parts of the electric power sector.

Given the significant environmental impacts associated with coal extraction and use, as well as declining demand in the United States since 2007, it's fair to ask whether coal has much of a future. Proponents of coal energy point to two types of technology change that might possibly prolong our utilization of this fuel. First, **clean coal technology** refers to a variety of approaches designed to remove contaminants from coal (such as mercury, sulfur, and arsenic) before it is burned. However, these technologies do nothing to address the issue of CO_2 pollution associated with coal use. For that, a second approach known as **carbon capture and storage (CCS)**, or **carbon sequestration**, is being proposed and tested. CCS involves technologies that can capture CO_2 emissions from coal burning before it leaves the smokestack. This CO_2 gas is then converted to a liquid and pumped underground for long-term storage. Early tests of CCS have had mixed results, but they have also proved to be quite expensive. This added expense undercuts one of the only advantages coal has in its favor: its relatively low price. Therefore, it's not clear whether the current decline in coal use, at least in countries like the United States, will ever be reversed.

7.4 Oil

Most people alive today have lived their entire life in what could be called the “age of oil.” Not only are we reliant on oil for our cars and transportation, we also depend on this resource in countless other ways. Oil is the raw material for many forms of plastic and synthetic fibers, and our industrial agricultural system could not operate without massive inputs of oil for fertilizer production. Therefore, it’s critical to consider the ways in which we extract and utilize oil, its environmental impacts, and whether we are nearing a period of “peak oil.”

Today’s oil deposits originate from the remains of phytoplankton and other microorganisms that lived in shallow seas and swamps hundreds of millions of years ago. As these organisms died and sank to the bottom, they formed thick layers of organic material that was eventually buried under layer after layer of sediment. As this organic material was subjected to increased heat and pressure, it was transformed into a waxy substance known as *kerogen* and then eventually into oil or natural gas, depending on temperatures and pressure levels. Oil collects in underground or underwater **oil reservoirs**, where it is trapped under a layer of impermeable rock that holds it in place and prevents it from seeping upward. Despite what the name sounds like, an oil reservoir is not a large pool of liquid oil but rather a porous rock formation that holds small drops of oil in its pores the way a sponge holds water. The current geographic distribution of large-scale oil deposits reflects those areas of the world that have the right geological conditions to have allowed oil to form millions of years ago and collect in oil reservoirs.

The *BP Statistical Review of World Energy* estimated global oil consumption in 2017 to be roughly 36 billion barrels. BP also reported global proven reserves of oil at the end of 2017 of 1,696 billion barrels, resulting in an R/P ratio of a little under 50, meaning that at current rates of consumption we have roughly 50 years of oil remaining. Two factors could lead to this number either overestimating or underestimating how many years of oil supply we actually have left. On the one hand, global demand for oil has been increasing at rapid rates, and this could mean we deplete reserves faster than expected. On the other hand, new drilling and oil extraction technologies could make oil deposits that are currently not counted in proven reserves available for exploitation, extending the life span of global oil reserves.

Extraction

Oil is extracted from underground reservoirs by drilling oil wells. When an oil reservoir is first tapped, there tends to be enough natural pressure in the deposit to push the oil up to the surface. This first volume of oil extracted from an oil well through natural pressure is known as **primary oil recovery**, and about 20% to 30% of oil in a reservoir can be extracted this way. Oil companies will then make use of **secondary oil recovery** techniques, such as injecting fluids into a reservoir to increase pressure, in order to extract another 10% to 20% of the oil in a deposit. Since many major oil deposits around the world have already gone through primary and secondary oil recovery processes, oil companies are now using even more extreme measures known as **tertiary oil recovery** (for example, injecting heated fluids or gases into an oil reservoir) to extract another 10% to 20% of oil from a reservoir. As one would expect, the EROI for oil extraction declines as oil companies move from primary to secondary and eventually tertiary oil recovery techniques. Primary oil recovery practices may have an EROI of 25:1, but this declines to about 10:1 for secondary oil recovery and as low as 5:1 for tertiary oil recovery. As a result, oil companies will typically resort to tertiary oil recovery techniques only when oil prices are high enough to justify the extra effort and expense.

dan_prat/iStock/Getty Images Plus

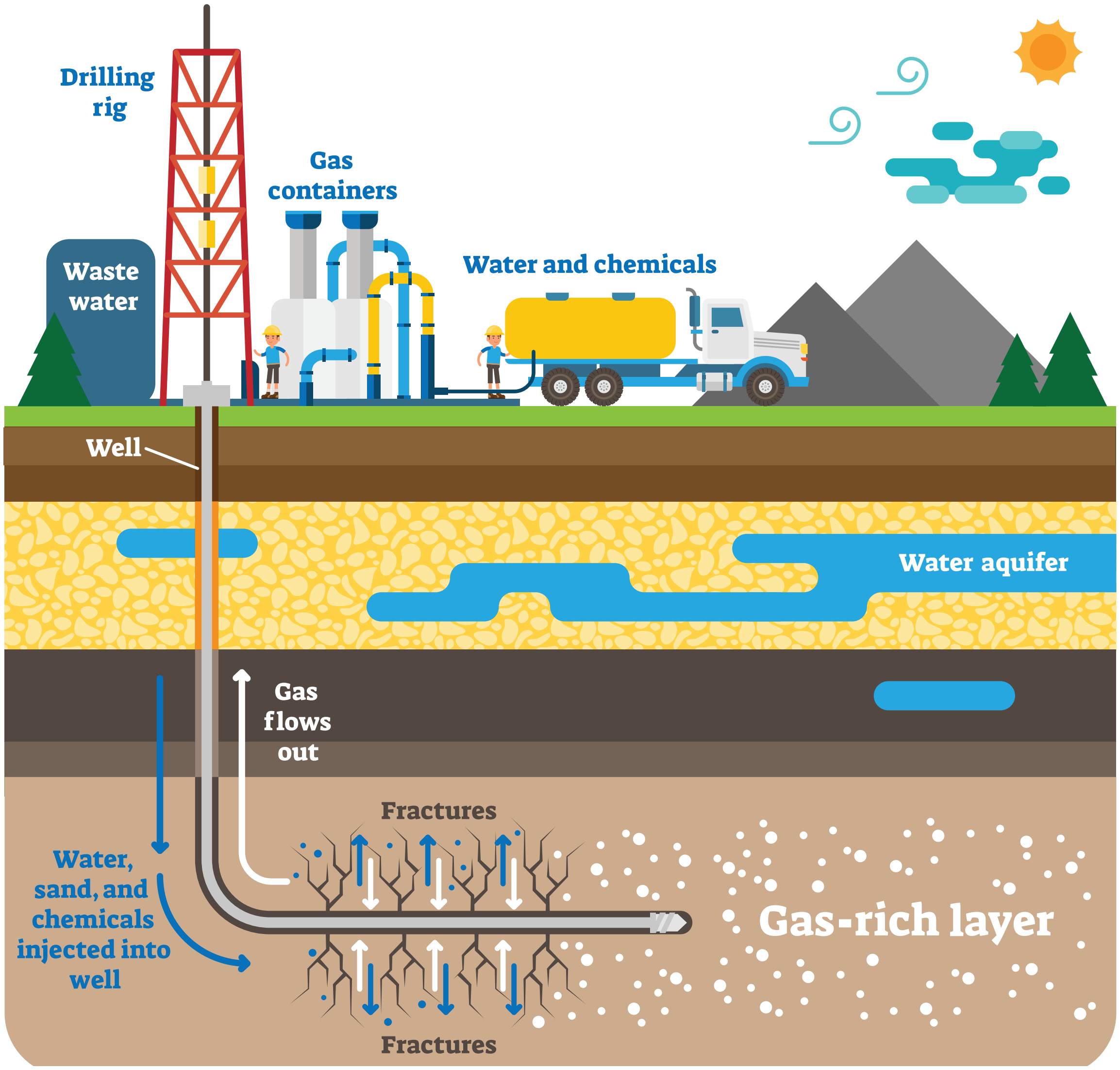
The tar sands operation in Alberta, Canada, is massive.

Another trend in global oil production is the increasing exploitation of unconventional oil deposits from oil shale and oil sands (also called tar sands). **Oil shale** is a rock formation that holds oil but is not porous enough to allow movement of oil through the formation. In the past 20 years, oil companies have developed a technique known as **hydraulic fracturing**, or **fracking**, to remove oil and natural gas from shale deposits. In fracking, liquids mixed with sand are pumped into oil shale deposits under extremely high pressures. This fractures and cracks the shale formations, while the sand keeps the cracks open just enough to allow the oil and gas to begin to flow (see Figure 7.2). **Oil sand**, or **tar sand**, formations are found near the surface and contain a tar-like substance known as *bitumen*. These sands can be heated to extract the bitumen, which can be refined into oil. Large-scale tar sand production in Alberta, Canada, supplies oil refineries in the United States via the Keystone Pipeline. Expansion of the pipeline has been a highly controversial issue in the northern and central United States in recent years. Both oil shale and tar sand production have lower EROI rates than oil production from conventional deposits, and both of these techniques have greater environmental impacts as well. For example, we learned in Chapter 5 that fracking of oil shale formations is linked with water-quality problems. Tar sand production involves completely stripping the surface of any vegetation and is also linked with local water pollution problems.

Once oil is extracted from the ground, it still needs to be refined before it can be used. The raw material that comes out of the ground is known as **crude oil**, and oil refineries are used to break that material down into different petroleum products like jet fuel, gasoline, asphalt, and lubrication oil. **Oil refineries** are basically giant distillation plants where crude oil is heated in what are known as distillation columns. Roughly 70% of crude oil sent to refineries is converted into gasoline or diesel fuel, and these fuels are used almost exclusively in the transportation sector.

Figure 7.2: Fracking

Fracking, or hydraulic fracturing, involves pumping water, sand, and chemicals at extremely high pressures into shale oil and gas deposits. This causes the shale to crack and allows the oil or gas to flow to the surface.



Source: Adapted from normaals/iStock/Getty Images Plus.

Impact and Future

As with coal mining and use, oil extraction and use results in a number of environmental problems. Chapter 6 described the challenges associated with oil spills and oil pollution of the world's oceans. In addition, development of unconventional oil deposits like oil shale and tar sands results in habitat destruction, water and air pollution, and other environmental issues. Finally, burning petroleum products like gasoline and diesel produces some of the same air pollution and greenhouse gas emission problems as burning coal. However, burning petroleum products is somewhat less polluting than using coal to produce the same amount of energy.

The future of oil use will depend on a number of factors. As with coal and natural gas, ongoing use of oil for decades to come may be limited by the issue of global climate change and the need to control greenhouse gas emissions. Because oil is used mainly in millions of vehicles dispersed all over the world, CO_2 emissions cannot be captured and stored in ways that are being tested for coal-fired power plants. Finally, with only about 50 years of proven reserves of oil estimated to be available, there are questions about whether we are nearing a point of "peak oil." **Peak oil** refers to the point in time when global oil production and use reaches its highest point before beginning a period of permanent decline. For these reasons—and because of the significant environmental impacts associated with oil extraction, transport, refining, and use—many energy experts are calling for a more rapid shift away from internal combustion engines to a greater reliance on EVs.

7.5 Natural Gas

Natural gas has a geologic origin similar to that of crude oil, except that it came about in locations where ancient organic material was buried deeper underground and subjected to even higher temperatures and pressures. As a result, natural gas deposits that we exploit today are often located in the same geographic regions as oil deposits. In fact, it used to be common practice for oil-drilling companies to simply "burn off" or flare natural gas that is released during the process of drilling for oil. Today, however, that natural gas is considered too valuable to waste in this way, so it is either captured and shipped to market through pipelines or reinjected into the oil deposit to increase pressure and the flow of oil.

Natural gas consists mainly of methane (CH_4) and is generally a cleaner burning fuel than either oil or coal. Burning natural gas produces only about half of the CO_2 as burning the energy equivalent of coal. This is one of the reasons why demand for natural gas has been growing worldwide, and specifically why natural gas has been displacing so much coal used in the electric power sector in the United States. The share of natural gas in the global energy economy increased from 22% in 2007 to 24% in 2017, according to the *BP Statistical Review of World Energy*. In the United States the share of natural gas has increased from 23% to 29% in the same time period.

Current global proven reserves of natural gas are estimated to be 194 trillion cubic meters (254 cubic yards), and global consumption rates are 3.67 trillion cubic meters (4.8 cubic yards) a year. This yields an R/P ratio of 53 years. In the United States the current R/P ratio is only about 12, suggesting only about 12 years of natural gas supply remaining at current rates of consumption. However, as we'll see in the following section, new natural gas extraction technologies like fracking are expanding proven reserves in many places. Some of the largest remaining deposits of natural gas are in Russia, Iran, Qatar, and Turkmenistan.

Extraction

Like oil, natural gas is extracted from underground deposits by drilling wells, and like oil, hydraulic fracturing (or fracking) is being used to extract natural gas from shale deposits. Once natural gas is pumped out of a reservoir, it is shipped by pipeline to a refinery, where it is cleaned of impurities. From there, natural gas is shipped to end users like electric power plants or residential furnaces through even more pipelines. In the United States about 34% of natural gas supply is used for electric power production, 16% for home heating and hot water, 12% for commercial applications, 3% for transportation (mainly natural gas–powered city buses), and 35% for industrial purposes (such as raw material for plastic, synthetic fiber, and fertilizer production).

One challenge with natural gas is that, unlike oil, it cannot be easily shipped across oceans. As a result, billions of dollars are being invested in facilities to convert natural gas into a liquid compound known as *liquefied natural gas (LNG)*. LNG is produced by chilling natural gas to −160 °C (−260 °F). Once chilled to this temperature, LNG takes up only about 1/600 the space of its gaseous form. LNG can then be shipped across oceans in specialized tankers and converted back to a gaseous form in facilities in the receiving country. Converting natural gas to LNG does require more energy, which therefore lowers the EROI for this energy source.

Impact and Future

The future for natural gas as an energy source will depend in large part on how this fuel is extracted and utilized. Because natural gas produces so much less CO_2 than an equivalent amount of coal, it's often described as a clean energy source that can act as a "bridge" to an energy future powered mainly by renewable sources. The clean energy bridge argument for natural gas is used as justification for increased hydraulic fracturing of shale deposits in places like North Dakota (Bakken shale deposit), Texas (Barnett shale deposit), and Pennsylvania (Marcellus shale deposit). Natural gas proponents correctly point out that gas extracted from these shale deposits is displacing coal in electric power plants and thereby helping the United States reduce its CO_2 emissions. However, the clean energy bridge justification has been called into question based on a 2018 report published in the journal *Science*. That report found that methane (CH_4) leaks from natural gas wells, pipelines, and other facilities were 60% higher than previously estimated (Alvarez et al., 2018). Because methane is also a greenhouse gas that can be up to 80 times more effective at trapping heat than CO_2, some of the clean energy advantages of natural gas use appear to be canceled out.

7.6 Nuclear Energy

All three fossil fuels—coal, oil, and natural gas—face some of the same challenges. Fossil fuels are nonrenewable and will not last forever. The most abundant of these fuels, coal, is also the dirtiest and most polluting. Extraction and use of all fossil fuels have immediate environmental impacts in the form of habitat destruction and water and air pollution—as well as long-term impacts in the form of climate change and global warming.

The remainder of this chapter will focus on the changes we need to make and the renewable energy sources that need to be developed and deployed globally to avoid the worst consequences of climate change. But first we will explore a source of energy that some say will play a critical role in the transition away from fossil fuels. **Nuclear energy**, or **nuclear power**, is electricity produced through a nuclear reaction. Because nuclear power can generate electricity without directly emitting carbon dioxide or other greenhouse gases, some have touted it as a "climate-friendly" source of energy. However, concerns over nuclear safety, the proper disposal of highly radioactive nuclear waste, and the high cost of nuclear construction have all combined to hinder a more rapid development of this energy source.

History

The nuclear age began with the detonation of two atomic bombs over Japan near the end of World War II in 1945. In the years after the war, scientists began harnessing the same basic technology used to produce atomic bombs in order to develop nuclear energy. The first commercial nuclear power plants went into operation in the 1950s, and at the time it was expected that this energy source would produce electricity so inexpensively that it would be "too cheap to meter." Optimism over the future of nuclear power continued into the 1960s and 1970s as electric power companies placed hundreds of orders for new plants.

The rate of growth in nuclear power plant construction began to ease, however, due to rising construction costs, public worries over nuclear safety, and questions about what to do with growing stockpiles of nuclear waste. Nuclear accidents at Three Mile Island in Pennsylvania in 1979 and Chernobyl in Ukraine in 1986 underscored these concerns, and nuclear power production slowed further. On March 11, 2011, an earthquake and tsunami off the coast of Japan caused radioactive material to pour out of the Fukushima Daiichi Nuclear Power Plant complex into the surrounding air and sea, reigniting the debate over the safety and future of nuclear energy.

Animaflora/iStock/Getty Images Plus

Nuclear energy is touted by some as climate friendly because it produces electricity without emitting carbon dioxide. However, nuclear facilities are costly to construct, potentially dangerous to maintain, and result in radioactive waste that must be handled with great care.

Today nuclear power provides about 10% of global electric power production, down from a high point of 17% in the mid-1990s. The United States has the highest number of nuclear power plants at 100, followed by France (58), Japan (43), China (36), and Russia (36). Of these countries, France derives the highest percentage of its electricity from nuclear power, with this energy source meeting 72% of that country's electricity demand.

How It Works

While the specific design of nuclear power plants varies across countries, they all operate on the basic principle of **nuclear fission**. Nuclear fission occurs when the nucleus of an atom is split to form two smaller nuclei, releasing energy in the process. To generate electricity, nuclear power plants initiate and control nuclear fission inside devices known as **nuclear reactors**.

In most reactors, nuclear fission starts with uranium-235 (U^{235}). U^{235} is created when uranium is mined and purified to reach a concentration that can sustain a series of nuclear fissions, known as a **nuclear chain reaction**. Uranium atoms are unstable and will split, or undergo fission, when struck by subatomic particles known as neutrons. Neutrons are released in a reactor core to split uranium atoms, in the process releasing energy and more neutrons. Those neutrons then trigger even more splitting or fission of other uranium atoms, releasing even more energy and neutrons. This sets in motion a nuclear chain reaction that releases tremendous amounts of energy in the process. In order to prevent this chain reaction from getting out of control, reactor cores also contain a cooling solution or moderator that slows the reactions down. They also have control rods made of material like boron that absorb neutrons and help slow or control the reaction. When the earthquake and tsunami struck the Fukushima nuclear complex in Japan, it crippled the cooling system in the reactor core of the plant. The runaway nuclear chain reaction then led to a nuclear "meltdown" and the release of radioactive material.

The entire purpose of generating a controlled nuclear chain reaction is simply to boil water. The energy released during fission heats water in the reactor core to a high enough temperature to produce steam. That steam is used to spin a large turbine attached to an electric generator, producing electricity. The same basic idea is at work in a coal- or natural gas–fired electric power plant, except that steam is produced in those plants by the combustion of these fuels rather than by a nuclear chain reaction.

Advantages and Disadvantages

In terms of the advantages and disadvantages of nuclear power, it's appropriate to compare this energy source to coal, since both are used almost exclusively to generate electricity (see Table 7.1).

Table 7.1: Coal versus nuclear

	Coal	Nuclear
Land disturbance from mining	Extensive, especially from mountaintop removal mining	Less extensive
Greenhouse gas emissions	Significant, a major source of CO_2 emissions globally	None from electric power generation; limited from plant construction and uranium mining
Other air pollution	Significant (see Chapter 8)	None from electric power generation; limited from plant construction and uranium mining
Radiation emissions	None or limited	None or limited, with the exception of severe accidents
Radioactive waste	None	Significant, requiring long-term storage and management
Worker health and safety	Serious risks and dangers from coal mining	More limited risks in mining, but potentially greater long-term risk in nuclear power plant operations
Health impacts on nearby residents	Significant due to air pollution	None or limited, with the exception of severe accidents
Effects of accident or terrorist attack	None or limited	Possibly catastrophic
Fuel supply	200–300 years, based on known estimates	Uncertain; depends on potential for reprocessing of used nuclear fuel

Both nuclear and coal-fired electricity generation start with mining—of uranium and coal, respectively. Because so much more coal has to be mined to generate the same amount of electricity, coal generally leads to greater habitat destruction and land disturbance. Both types of mining contribute to health risks for miners: black lung disease for coal miners and radiation exposure for uranium miners.

Once these fuels reach a power plant and are used to generate electricity, nuclear power is far cleaner than coal and basically produces no air pollution or CO_2 emissions. It should be noted, however, that mining uranium, enriching uranium, and building and operating a nuclear power plant do produce pollution and CO_2 emissions, even if the actual generation of electricity does not. In addition, nuclear power production results in radioactive waste that will be dangerous for thousands of years. This waste needs to be stored and monitored to prevent radioactive material from escaping to the surrounding environment.

Finally, nuclear power plants themselves become radioactive over time and have to undergo an expensive decommissioning process at the end of their operation. In addition, the radioactive material from the decommissioning process has to be stored safely for hundreds of years.

Impact and Future

Overall, nuclear power produces electricity with fewer immediate environmental impacts compared with coal. The main exception relates to radioactive waste management and disposal. One other difference, however, is the very small risk of a nuclear accident and what the consequences of such an event would be. Aside from large nuclear accidents—such as those at Three Mile Island, Chernobyl, and Fukushima—smaller incidents and minor radiation leaks are more common. This “small risk–big impact” reality of nuclear power is largely responsible for public opposition to this energy source and has also contributed to the rising cost of nuclear power.

The future potential of nuclear energy is highly uncertain. Many of the roughly 400 nuclear power plants currently generating electricity around the world are nearing the end of their expected operational life and will soon start to undergo decommissioning. The high cost of construction and financial risks associated with building and operating a new nuclear power plant have driven electric utility companies in the United States and other countries to cancel orders for new reactors. However, given the urgency of global climate change, some energy experts and even some prominent environmentalists are calling for a new look at nuclear energy. New reactor designs and so-called next-gen nukes that have inherent safety features and lower construction costs are also fueling renewed interest in nuclear power. The question remains as to whether public distrust of nuclear power and private sector nervousness about the financial risks can be overcome. A lot will depend on how rapidly the world can continue to develop renewable energy sources.

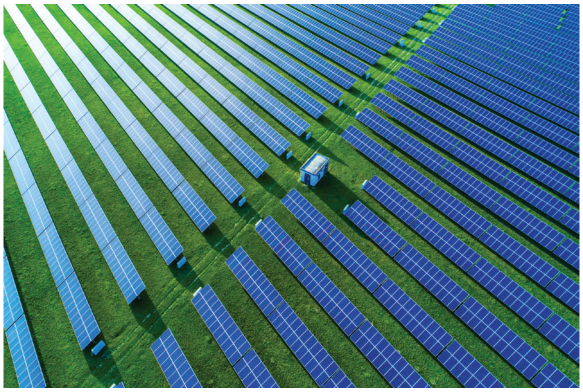
Learn More: The Debate Over Nuclear Energy

This TED Talk presents a debate over the need for nuclear energy between two experts in the field.

- https://www.youtube.com/watch?v=UK8ccWSZkic

7.7 The Energy Transition

Long before we ever “run out” of fossil fuels like coal, oil, and natural gas, we will have to transition away from a reliance on these fuels to different energy sources. Unless we do so, atmospheric concentrations of the main greenhouse gas carbon dioxide will reach levels exceeding 550 or 600 ppm, triggering catastrophic climate change with massive and unpredictable consequences. At current rates of consumption, this means that we have just a few decades to achieve roughly an 80% reduction in our use of fossil fuels, since our energy choices will become increasingly "carbon constrained." While we have undergone energy transitions in the past, the transformation of the energy landscape in the decades ahead will be far more massive and will have to occur faster than anything we have ever witnessed before. It's no exaggeration to state that we are on the verge of not just an energy transition but an actual energy revolution.


valio84sl/iStock/Getty Images Plus

Solar farms such as this one might well play an important role in the energy transition.

The energy sources and technologies needed to replace fossil fuels are currently available, commercially viable, and seeing increased use the world over. These include what are sometimes referred to as "traditional" renewable energy sources like hydropower, geothermal energy, and biomass energy. They also include "new" renewables like solar energy, wind power, and ocean energy. These renewable energy sources have a massive potential. The total energy contained in one hour of sunlight striking the Earth's surface is more than all the commercial energy consumed on the planet in an entire year. Likewise, the energy contained in the wind blowing at any time across the planet is more than 15 times the global energy demand in that moment. However, unlike the highly "energy-dense" fossil fuels, renewable energy sources are diffuse and intermittent. We have to deploy technologies like solar panels and wind turbines over wide areas to capture enough of this energy to meet demand and to develop methods to collect and store that energy for later use.

The renewable energy transition or revolution faces a number of other challenges as well. As with all new technologies, the development and deployment of renewable energy is held back by uncertainties over the technology itself. As these technologies have become more widespread, some of the hesitation associated with adopting them has also diminished. Second, renewable energy sources have often been more expensive than fossil fuel energy sources, and this has limited investment in and adoption of these technologies. That situation has changed rapidly in just the past decade as renewable energy sources like wind and solar have become cost competitive with fossil fuels in most applications. Third, recall the concept of external costs and the idea that all fossil fuel use (especially coal) imposes externalities in the form of air pollution, water pollution, health impacts, and habitat destruction. The presence of these external costs means that fossil fuels appear to be cheaper than they actually are, or put a different way, renewable energy sources might be even more cost competitive than we believe them to be.

Fortunately, many of these challenges that have been holding back the adoption of renewable energy sources are diminishing, and we are seeing examples of cities, states, and even entire countries meet a growing percentage of their energy demand through renewable sources. For example, the city of Orlando, Florida, is covering rainwater collection ponds with solar panels and has set a goal of meeting all its energy needs from "carbon-free" sources by 2050. The state of California is on track to generate 50% of its electricity with renewable energy sources within the next few years. And countries like Germany and Denmark are already meeting one third or more of their electricity needs with renewable energy sources like solar and wind.

Much of the remainder of this chapter will take a closer look at the renewable energy technologies that will play the biggest part in the energy transition away from fossil fuels. This includes solar energy, wind power, biomass energy, hydropower, geothermal energy, and ocean and tidal energy. However, we'll start the discussion of renewables with a focus on energy efficiency and conservation. By first reducing levels of energy demand through better lighting, appliances, windows, and insulation, we can reduce the quantity and magnitude of the renewable energy devices that need to be deployed to meet that energy demand.

Learn More: The Energy Transition

In the first link, energy theorist Amory Lovins lays out a 40-year plan to move away from our dependence on oil in an engaging TED Talk. The second website provides examples of how the energy transition is under way all over the world.

- https://www.youtube.com/watch?v=ZHOyfyGwpes
- https://energytransition.org

7.8 Energy Efficiency and Conservation

Energy conservation and energy efficiency are related but are also different concepts. **Energy conservation** refers to a process of changed behavior that reduces energy consumption by, for example, turning down the heat or walking instead of driving. **Energy efficiency** is defined as achieving the same outcome—heating a room, driving to work—while using less energy in the process. Therefore, energy efficiency depends on changes in technology or conditions, such as better insulation or a more fuel-efficient vehicle.

Energy efficiency and conservation are sometimes referred to as the "fifth fuel" after coal, oil, natural gas, and renewable energy sources since they help us achieve desired energy outcomes. But energy efficiency and conservation are the most immediate and the least costly means for reducing greenhouse gas emissions from energy use. The logic behind the pursuit of energy efficiency and conservation is simple: Lowering energy demand means reducing the need to produce energy in the first place, regardless of where that energy is actually coming from. In other words, rather than focus on the energy *supply side* by increasing energy production, energy efficiency and conservation represent a shift in focus to the *demand side*. Put another way, it could be said that the most "environmentally responsible" power plant that can be built is the one that doesn't need to build. We can find examples of energy conservation and efficiency all around us.

Transportation Sector

In the transportation sector, designing communities and neighborhoods in a way that promotes walking, biking, and/or the use of mass transit options is a great way to promote energy conservation. Unfortunately, in many regions of the United States, the opposite is the case, and citizens are left with little choice but to rely on personal vehicles for most or all of their transportation needs. In terms of energy efficiency, internal combustion engines have become much more efficient over the past few decades. However, some of these efficiency gains have been canceled out by a move to greater use of sport-utility vehicles and trucks by consumers. In 1975 over 80% of the personal vehicles sold in the United States were cars, but today that figure is under 50%. As a result, the overall efficiency of the personal vehicle fleet in the United States has only increased from 22 miles per gallon (mpg) in 1985 to just under 25 mpg in 2017.

Looking into the future, greater use of gasoline–electric hybrid vehicles, plug-in hybrid automobiles, and electric vehicles is being touted as a way to reduce environmental impacts in the transportation sector. The gasoline–electric and plug-in hybrid vehicles are equipped with both an internal combustion engine and an electric motor powered by batteries. The gasoline–electric battery system is constantly recharged as the brakes are applied, whereas batteries in a plug-in hybrid are charged by plugging into an electric outlet. Both kinds of hybrid vehicles rely on the internal combustion engine for higher speed driving and battery power for slower speed, city driving. And both kinds of hybrid vehicles can achieve fuel efficiencies of 40 to 60 mpg. Finally, EVs depend entirely on battery power and emit no pollution or greenhouse gases when in operation. However, the overall environmental impact of a switch to EVs depends in large part on how the electricity used to charge the batteries is generated in the first place (see the *Close to Home* feature box).

Close to Home: Considering Sources and Benefits of Electricity

Electricity is an incredibly useful form of energy, and it can accomplish many of our daily tasks more efficiently than fossil fuels can. Consider car travel. A typical gasoline-powered car might be around 20% efficient. In other words, only 20% of the energy contained in gasoline is successfully harnessed to move things around. The rest is lost as waste heat to the surrounding environment. EVs use electric motors that can be more than 90% efficient (Hanley, 2018), so nearly all the electricity stored in a car's battery system can be converted into powering the car.

(continued)

Close to Home: Considering Sources and Benefits of Electricity *(continued)*

Heating buildings can be more efficient with electricity as well. Most homes use furnaces and boilers that warm air and water with natural gas or oil. Heat pumps are electrical appliances that can move heat from one location to another with incredible efficiency. In many situations, heat pumps can reduce energy use by 30% to 60% (U.S. Department of Energy, n.d.b). Because electricity is so efficient, many experts believe that electrifying our economy is one of the best things we can do for the environment. They argue that if we cook, heat, and transport ourselves with more electricity and fewer fossil fuels, we will require fewer energy resources and have less of an environmental impact.

However, there are some important factors to consider, including where the electricity comes from. Some places use emissions-free technologies like nuclear, wind, solar, and hydroelectric to produce electricity, but most locations still rely on coal and natural gas power plants. These fossil fuel sources are only 30%–50% efficient, so a lot of energy can be lost (and a lot of emissions can be produced) when we generate electricity in the first place. The benefits of electricity depend on the specific technologies that are supplying the electrical grid.

Consider the benefits of driving an EV in different locations in the United States. A typical U.S. car owner drives an average of 37 miles per day (Federal Highway Administration, 2018), which results in about 31 pounds of CO_2 emissions per day when using a typical gasoline-powered car (U.S. Department of Energy, 2018). EVs might emit anywhere from 0 pounds per day, if their electricity comes from an emissions-free power source, to 25 pounds per day, if their electricity comes from a coal-fueled power plant (U.S. Department of Energy, n.d.a, 2016). Twenty-five pounds per day is still an improvement, but in this case, it might make more sense to upgrade the power plant before investing heavily in a new transportation system.

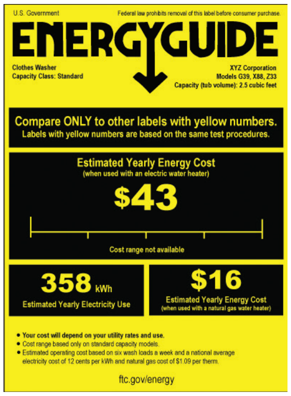
To explore the benefits of electricity use in different locations, take a look at the EPA's Power Profiler website. This resource contains data from electrical grid regions all over the United States. The mix of energy resources utilized by each region is provided in the Fuel Mix chart, and you can find where these regions are located by using the map toward the bottom of the page. Grid emissions are presented in the Emission Rates chart, which provides the pounds of CO_2 that are produced for every megawatt-hour of electricity. Using both charts, we can see that some regions, like the SRMW in Missouri and Illinois, rely predominantly on coal and create large amounts of greenhouse gas emissions. Other regions, like the NYUP in New York, utilize hydroelectric and nuclear technologies and produce much cleaner electricity.

You can also use the Power Profiler to explore your grid region in greater detail. If you enter your zip code on the left-hand side, the website will compare the fuel mix and emission rate in your grid region to those of the national average. To put your region's emission rate into perspective, the national average value is 998.4 pounds per megawatt-hour, which would result in roughly 13 pounds per day for the average EV owner. To find the driving impact of EVs in your location, just multiply your region's emission rate by the 0.0125 megawatt-hours per day that a typical EV will require.

Now that you have a better sense of where your electricity is coming from, do you think it is important to convert more energy systems to electricity in your location? Should your region focus on transitioning to cleaner forms of power production first? Are there other ways you can capitalize on the environmental benefits of electricity to make your lifestyle more sustainable?

The Building and Residential Sector

Energy conservation and efficiency can also be achieved in the *building and residential sector*. While turning off lights and controlling the thermostat are commonsense ways to conserve energy (and save money), they are just the tip of the iceberg in reducing building and residential energy consumption. Energy efficiency investments like adding insulation, installing energy-efficient windows, switching to energy-efficient appliances, and using energy-efficient lighting can dramatically lower energy consumption and energy bills in just about any home or building. So-called net zero energy buildings are constructed to be highly energy efficient and outfitted with renewable energy devices like solar panels, with the overall goal of having the building produce as much energy as it consumes.



U.S. Government
Federal law prohibits removal of this label before consumer purchase.

ENERGYGUIDE

Clothes Washer
Capacity Class: Standard

XYZ Corporation
Models G39, X88, Z33
Capacity (tub volume): 2.5 cubic feet

Compare ONLY to other labels with yellow numbers.
Labels with yellow numbers are based on the same test procedures.

Estimated Yearly Energy Cost
(when used with an electric water heater)
$43

Cost range not available

358 kWh
Estimated Yearly Electricity Use

$16
Estimated Yearly Energy Cost
(when used with a natural gas water heater)

- Your cost will depend on your utility rates and use.
- Cost range based only on standard capacity models.
- Estimated operating cost based on six wash loads a week and a national average electricity cost of 12 cents per kWh and natural gas cost of $1.09 per therm.

ftc.gov/energy

Consumer Information, Federal Trade Commission. This image is not subject to copyright protection.

EnergyGuide labels such as this one are intended to help consumers make informed decisions, but people don't always understand the information being presented. The key is to focus on the "estimated yearly energy cost" and compare that figure to other appliances being considered.

Despite the apparently obvious advantages to promoting energy conservation and achieving greater energy efficiency, there are a number of barriers to doing so. First, becoming more energy efficient can often involve significant *up-front investments*. While insulating a home, installing energy-efficient windows, or buying a more efficient refrigerator can save a consumer money over the long term, they require spending money now, and not everyone can afford such investments. Likewise, it's not always clear to consumers what the most energy-efficient options are. While many of us are familiar with the yellow EnergyGuide labels found on new appliances, we're not always able to process that information in a way that allows for a true and accurate comparison across different products. Unfortunately, it appears that these up-front cost and information barriers to energy efficiency have a disproportionate impact on low- and moderate-income households, exactly the families that would benefit the most from lower energy consumption and energy bills (Bagley, 2019). Government programs offer one way to overcome this challenge. For example, one program in California directs a portion of energy tax revenue to clean energy projects in low-income neighborhoods.

Learn More: Energy Justice in California

California's effort to help fund investment in energy efficiency and renewable energy in low-income communities is an example of what's being called "energy justice." Learn more about the program at these sites.

- https://calepa.ca.gov/envjustice/ghginvest
- https://e360.yale.edu/features/green-upgrade-how-california-is-pioneering-renewable-energy-justice-cap-and-trade

7.9 Solar Energy

Of all the renewable energy sources discussed in this chapter, the potential for **solar energy**—energy from the sun—is probably the greatest. In addition to being abundant, solar energy helps drive processes that enable other forms of renewable energy; for example, the wind, the water cycle (hydropower), and photosynthesis (biomass energy). The main challenge we face with solar energy is finding ways to take this abundant—but also diffuse and intermittent—energy source and concentrate it in a form that we can use in transportation, building, industrial, and commercial applications. This requires technologies that can capture, collect, convert, store, and transport solar energy when and where it is needed.

How It Works

One major benefit of solar energy is that it can be utilized in a number of different ways. **Passive solar energy** refers to approaches that use sunlight directly without any mechanical devices, such as when sunlight is used to illuminate or heat interior spaces. **Active solar energy** approaches capture sunlight using mechanical devices and then convert it to useful heat or electric power (referred to as **solar power**).

Passive Solar Energy

Human societies have long been aware of the potential for passive solar energy applications. A well-known example of this is the Anasazi cliff dwellings found in the southwestern United States. These dwellings are located on south-facing cliffs with rock overhangs, providing direct solar heating of the space in cooler winter months when the sun is low in the sky and shade in the summer months from the hot desert sun.

bboserup/iStock/Getty Images Plus

The ancient Anasazi cliff dwellings are an example of passive solar construction in that they provide optimum solar heating and sun protection at different times of the day and year.

In modern homes the same principle can be achieved by orienting the building to receive maximum sunlight in winter months and less during the summer. For example, large areas of south-facing windows will let in the winter sun and help warm interior spaces. Extended overhangs or window treatments (such as solar-blocking shades that are easy to open and close) can then be used to block some of that sun from entering in the summer to help keep the space cool. Deciduous trees can also be planted around a building, since they drop their leaves in the winter—allowing sunlight through—but shade the building in the summer.

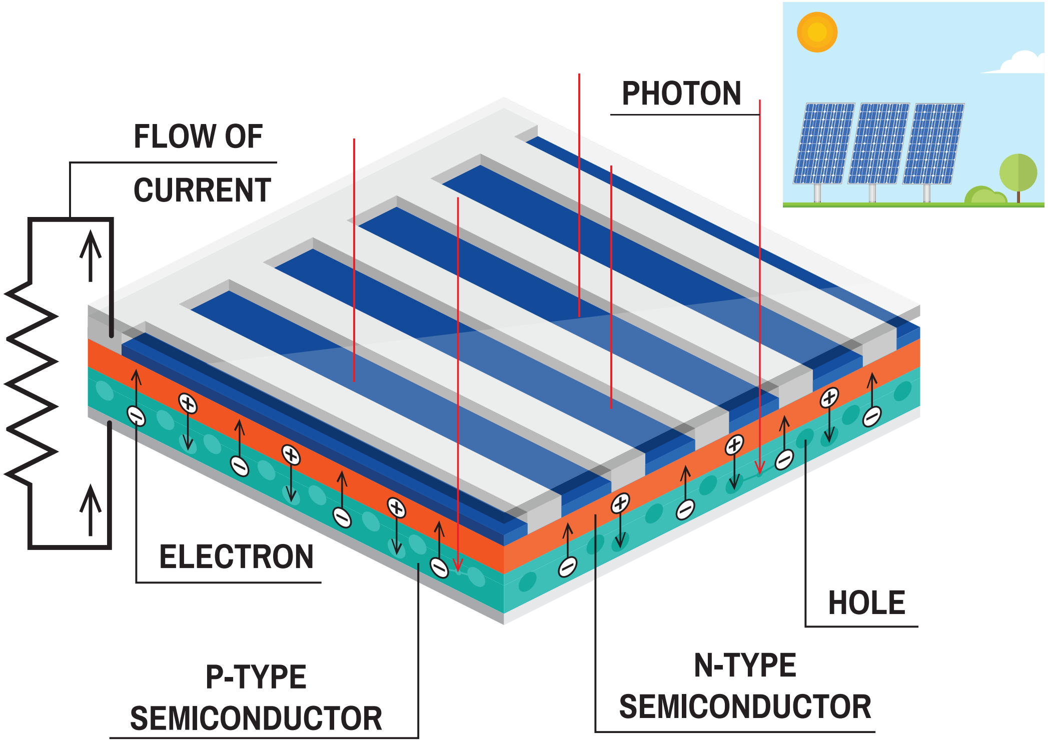
Active Solar Energy

Active solar energy devices include flat plate solar collectors for space heating or hot water production. Flat plate collectors are mounted on rooftops and consist of a glass surface, dark-colored backing, and a series of tubes for circulating water or air. Sunlight striking the collector heats the water or air, which is then pumped into the building and used to provide hot water to the tap or heat for space heating. Flat plate solar collectors for hot water heating are relatively inexpensive and easy to install, and they are especially popular in sunny, warm climates.

Perhaps the greatest potential for solar energy, however, is with the generation of electricity, or solar power. Solar energy can be used to generate electricity through two main approaches—solar photovoltaic and concentrating solar power technologies. Solar **photovoltaic (PV) cells** convert sunlight into electricity (see Figure 7.3). The *photovoltaic effect* occurs when light energy causes certain materials to emit electrons and generate an electric current. Most PV cells are made of two silicon plates and small amounts of other metals. As sunlight hits a PV cell, it strikes one of the silicon plates and releases electrons, and as these electrons move toward the second silicon plate, they create an electric current. An individual PV cell is a tiny, wafer-shaped plate just a couple of inches across that is able to generate an electrical current roughly equivalent to that of a size D flashlight battery.

Figure 7.3: Photovoltaic effect

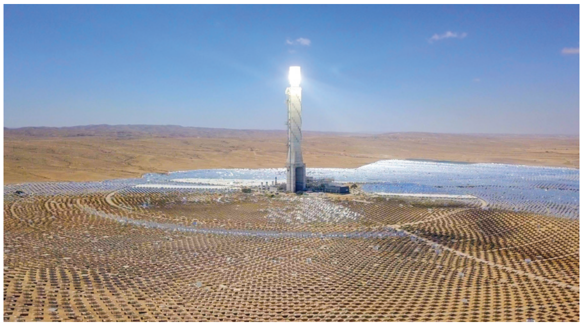
Solar PV panels are made out of PV cells and are used to generate electricity.



Source: Adapted from ser_igor/iStock/Getty Images Plus.

PV cells are grouped into modules a few feet across, and modules are combined to form a *PV panel*. PV panels are then grouped together to form *PV arrays*, which can range in size from a handful of panels on a residential rooftop to thousands of panels deployed across the landscape by electric utility companies in what are known as *PV farms*. The Longyangxia Dam Solar Park in China and the Kurnool Ultra Mega Solar Park in India are believed to be the largest solar PV complexes in the world, and both occupy a land area of roughly 25 square kilometers in size (about the size of 260 football fields). Each of these PV farms deploys about 4 million solar PV panels and generates enough electricity to power approximately 200,000 households.

Concentrating solar power (CSP) systems are another way to generate electricity from the sun. CSP systems are large-scale complexes that use mirrors to concentrate the sun's rays on a tank or series of pipes filled with water or another fluid. The concentrated sunlight is so intense that it brings this fluid to a boil, producing steam. The steam can then be used to spin a turbine and generate electricity in much the same way as is done in a conventional or nuclear power plant. The world's largest CSP system (also about 25 square kilometers in size), the Noor complex, is located in Morocco and can generate enough electricity to meet the needs of over 1 million people. The largest CSP facility in the United States is the Ivanpah Solar Electric Generating System in the Mojave Desert of California; it is about two thirds the size of the Noor complex.



liorpt/iStock/Getty Images Plus

This concentrating solar power system uses thousands of mirrors to focus the sun's rays on a collector tower.

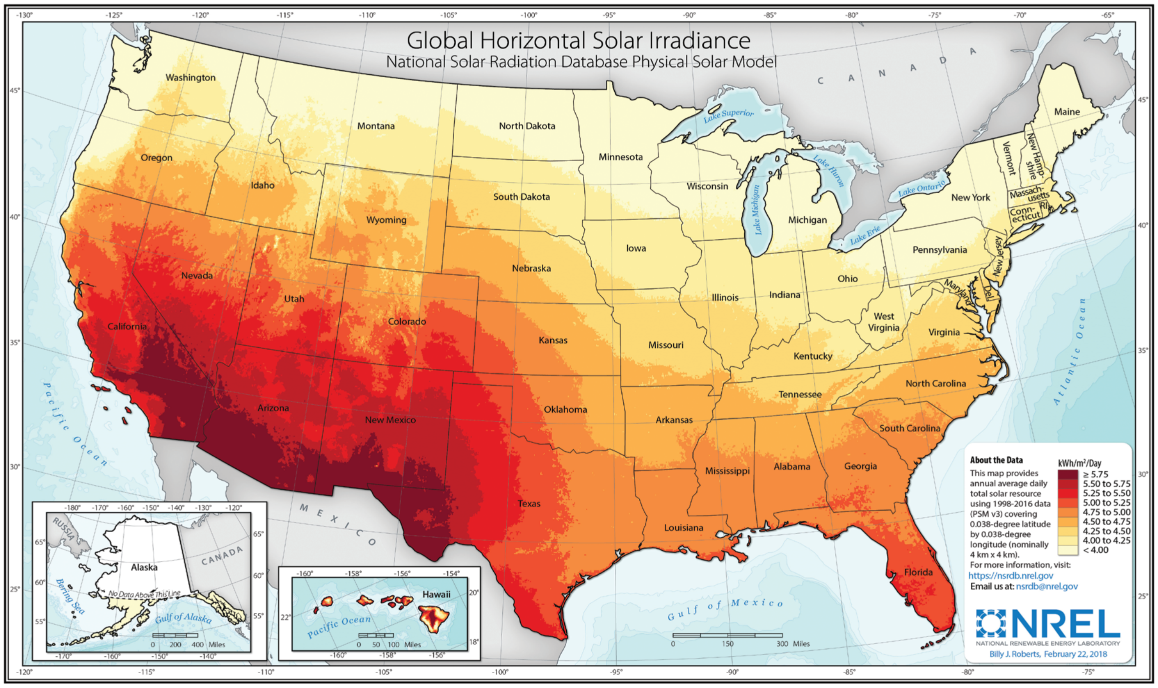
Advantages and Disadvantages

Solar energy offers a number of significant advantages over fossil fuel energy sources. Solar is infinitely renewable and does not directly produce any air pollution or greenhouse gases. Solar PV panels are easily adaptable and can be installed on roofs, over parking lots, in abandoned industrial areas, or across unused farmland and open space. The solar energy industry employs close to 250,000 Americans, more than double the number employed in this sector in 2012 and roughly 70,000 more than are employed in the entire coal industry. The solar energy industry also contributed almost $20 billion to the U.S. economy in 2018.

At the same time, solar energy has a number of disadvantages and faces a handful of challenges. Solar energy is unevenly distributed (see Figure 7.4) and may not be as economical in some places as in others. At the household level, installing a rooftop solar PV system can have an up-front cost of $10,000 or more. While such a system will pay for itself over time, the ability of many households to afford such an up-front investment is limited. Large-scale solar PV farms and CSP complexes are generating electricity at prices that are nearing equivalency with coal- and natural gas–fired power plants, but they are still slightly more expensive than these energy sources (ignoring the external costs associated with fossil fuel use). Finally, while solar power is essentially pollution free once in operation, the manufacture and production of solar PV and CSP systems do involve some fossil fuel energy consumption and environmental impacts. These impacts are small compared to those associated with the direct use of fossil fuels, but they need to be taken into consideration.

Figure 7.4: U.S. solar resource map

Solar energy is unevenly distributed. In this map of the United States, the darker the area, the more solar energy that region receives.



*Source: "Solar Maps," by National Renewable Energy Laboratory, n.d. (**https://www.nrel.gov/gis/solar.html**).*

The solar energy sector has seen rapid growth in the United States and worldwide in recent years, and there is every indication that this trend will continue. New solar installations have accounted for 30% to 40% of all new electric generating capacity installed in the United States since 2013, driven by consistently declining prices for solar PV and CSP systems. Solar power systems already generate enough electricity to power over 12 million homes in the United States, and there are now more than 2 million solar installations across the country.

7.10 Wind Energy

Humans have long been aware of the power and potential of wind energy, harnessing it for thousands of years to sail ships and turn windmills for grinding grain or pumping water. As with solar energy, the worldwide potential for wind energy is great, but as with solar, the challenge is how to capture, convert, and transport that energy to where it's needed when it's needed. Wind energy could actually be considered a form of solar energy, since winds are caused by uneven heating of the planet's surface combined with differences in topography and the Earth's rotation. As a result, some areas of the planet are better suited for wind energy development than others.

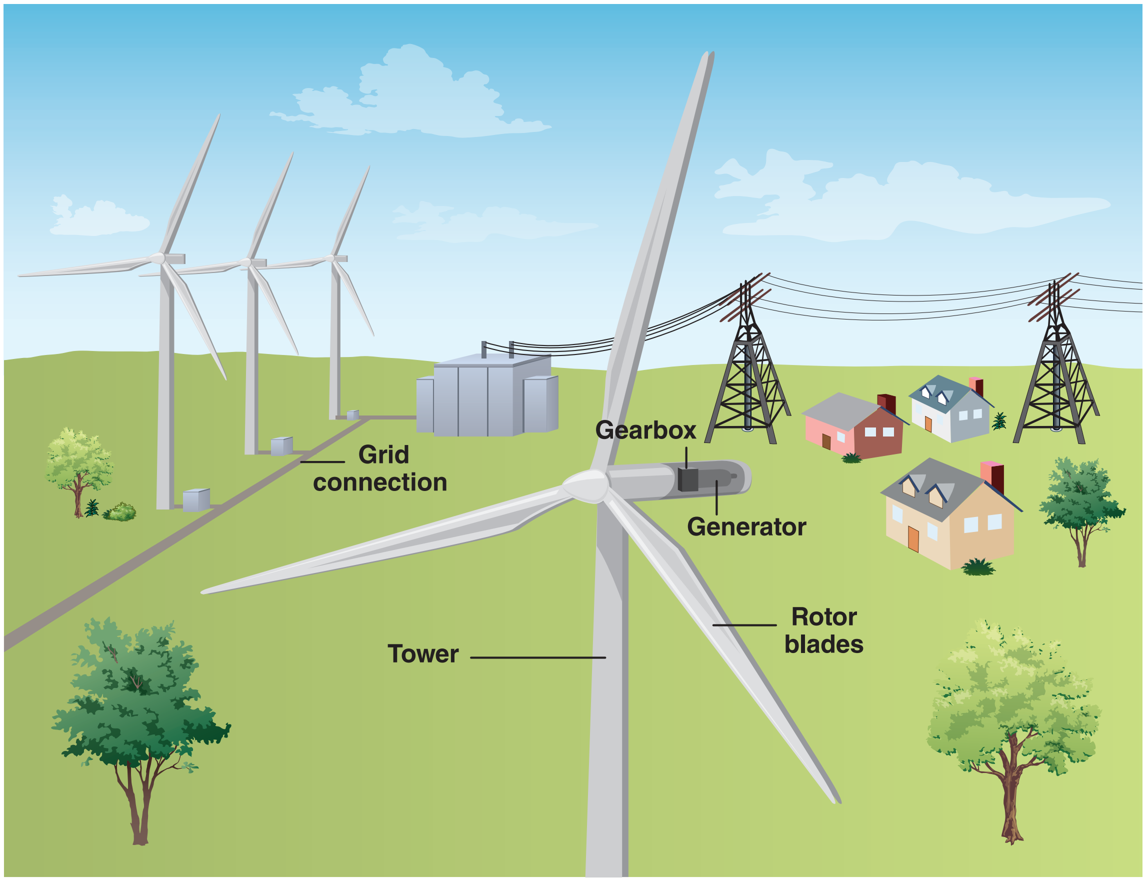
How It Works

To convert wind energy into electrical **wind power**, we make use of wind turbines. **Wind turbines** are large mechanical assemblies that convert the wind's kinetic energy into electrical energy (see Figure 7.5). Electric utilities and wind power companies mount wind turbines on tall towers to take advantage of higher wind speeds and less turbulent wind conditions higher above the ground. As winds hit the blades or rotor of a wind turbine, the kinetic energy in the wind begins to spin the blades. The rotor blades are mounted on a shaft connected to a gearbox and generator; as the shaft rotates, it drives the generator, producing electricity. Today's utility-scale wind turbines are massive, mounted as high as 220 meters (720 feet) above the ground and with rotor blades that are 100 meters (330 feet) in length. A single wind turbine of this size can generate enough electricity to power as many as 5,000 homes. However, electric utilities typically cluster wind turbines together in a specific geographic area known as a *wind farm*. The largest wind farm in the world is located in China, where 7,000 wind turbines produce enough electricity to power over 5 million households. The largest wind farm in the United States (covering roughly 13 square kilometers, or 5 square miles) operates 600 turbines in Kern County, California, and generates enough electricity to power more than 1 million homes.

Wind power is the fastest growing source of electricity generation in the world today and currently meets about 4% of global electricity demand. China has the largest installed wind power *capacity* of any country in the world, but the United States is still the top *producer* of electricity from wind. This is because China has been building new wind farms in more remote regions of that country without fully integrating them into the national electric power grid. Other leaders in wind power production include Germany, Spain, India, and the United Kingdom. In terms of the *share* of overall electricity produced by wind power, Denmark, Portugal, Spain, Ireland, and Germany top the rankings. With nearly 40% of its electricity coming from wind power, Denmark is proving that with the right planning and management of the electric power grid, even an intermittent source of energy like wind can make a major contribution to meeting electrical demand.

Figure 7.5: Wind turbine

Wind turbines convert the wind's kinetic energy into electrical energy.



*Source: Adapted from "The Inside of a Wind Turbine," by Office of Energy Efficiency and Renewable Energy, n.d. (**https://www.energy.gov/eere/wind/inside-wind-turbine**).*

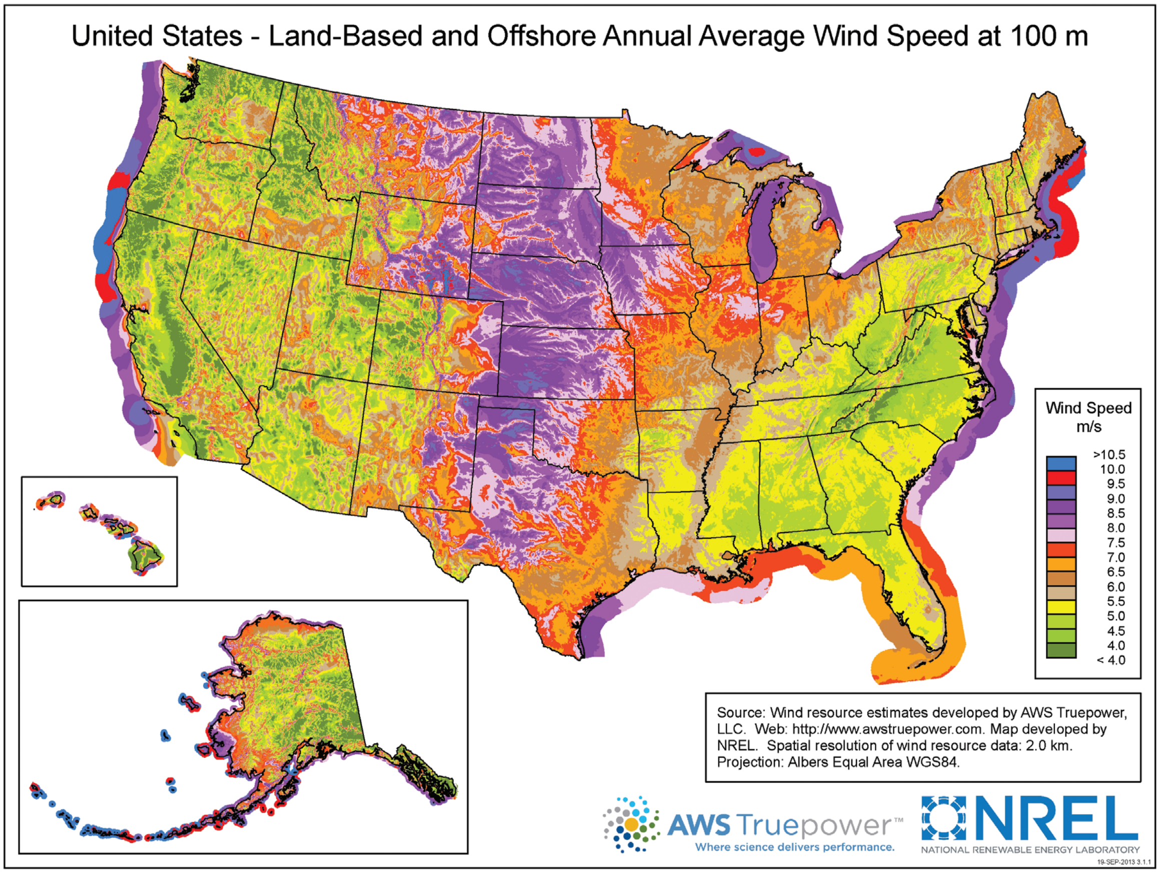
Advantages and Disadvantages

Wind energy offers many of the same benefits and advantages as solar power—it is non-polluting, does not directly result in greenhouse gas emissions, and employs over 100,000 Americans. At current rates of production, wind power in the United States is responsible for a reduction in greenhouse gas emissions that is the equivalent of taking over 20 million cars off the road. Since wind turbines can be placed on open fields or grazing lands, they can also be a good source of additional income for farmers and ranchers, who can receive annual royalty payments of $3,000 to $4,000 for every turbine placed on their land. Lastly, wind turbines are a relatively efficient way to generate electricity, with an EROI of over 20:1.

But just as with solar energy, wind power also has some drawbacks and challenges. Like solar, wind energy is intermittent and unevenly distributed (see Figure 7.6), making it a more viable option in some regions than others. Another challenge is that some individuals find wind power facilities, especially large-scale wind farms and associated electrical transmission wires, to be aesthetically unpleasing. People living near wind farms may also complain about the noise from the spinning turbines, although sound measurements suggest they are no louder than many familiar background noises like refrigerators and nearby traffic. Lastly, wind turbines are known to be a cause of bird and bat deaths as a result of collisions, and the frequency of this problem is growing with the expansion of wind power. Proponents of wind power acknowledge this problem but also point out that the *thousands* of bird deaths each year from wind turbines are just a tiny fraction of the *millions* of deaths caused by domestic cats, auto traffic, and collisions with windows and buildings. Nevertheless, the wind power industry is paying increasing attention to issues of aesthetics, noise, and nearby bird and bat populations as it makes decisions about the appropriate siting and placement of wind turbines and wind farms.

Figure 7.6: U.S. wind resource map

Wind energy is unevenly distributed. In this map of the United States, wind speed is generally highest along the coasts and in the Midwest.



Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

*Source: "Wind Maps," by National Renewable Energy Laboratory, n.d. (**https://www.nrel.gov/gis/wind.html**).*

As the cost of generating electricity with wind turbines continues to decline, wind power production is expected to continue to increase. It's *already* the case that in locations with favorable wind conditions, the cost of producing electricity with wind turbines is lower than generating it in a coal, natural gas, or nuclear power plant. Because there is no "price" for the wind, the cost of producing wind power is also not subject to the same sort of market fluctuations in price experienced by coal- and natural gas–powered electricity production. In the years ahead, offshore wind farms located in areas of open water are expected to grow in importance. Offshore wind farms offer a number of advantages over onshore locations. Namely, offshore locations tend to have more consistent and higher wind speed conditions, and they can be located far enough off the coast to minimize noise and aesthetic concerns.

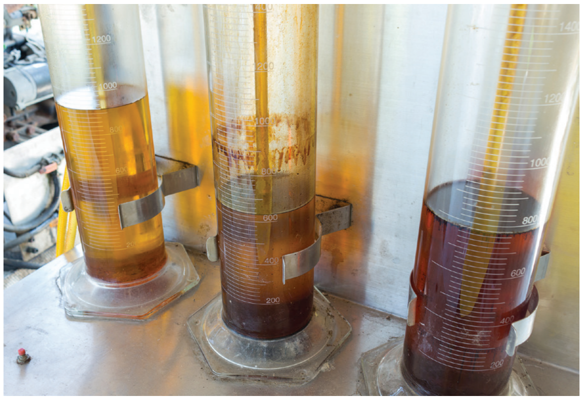
7.11 Biomass Energy

Of all the forms of energy described in this chapter, biomass energy has the longest history of human use. **Biomass energy**, or **bioenergy**, is any form of energy derived from living, organic material. Throughout history we have burned wood and other plant-based material to cook, illuminate the darkness, and keep warm, and wood was humankind's main source of energy until just a few hundred years ago. We can say that bioenergy is a form of solar energy since it originates with the chemical energy produced through photosynthesis.

How It Works

We can use bioenergy to generate heat and electricity or to create gaseous or liquid fuels. Direct combustion of firewood, charcoal, and agricultural residues for cooking and space heating is still widespread in many developing countries of the world. The FAO estimates that over 2 billion people worldwide still rely on these forms of "traditional" bioenergy. Worldwide consumption of firewood and other biomass energy in traditional applications still represents about 10% of global primary energy use each year. In addition, biomass energy in the form of wood waste and agricultural residues is used in larger scale facilities to generate electricity and for industrial heating purposes. For example, in the United States wood waste from sawmills and forestry operations is used to generate electricity and as a fuel in pulp and paper operations. In Brazil, the Philippines, and other tropical countries, the residue from sugarcane production, known as bagasse, is burned for electricity production and as an industrial fuel in sugar mills.

Biomass can also be converted to gaseous fuels (**biogas**) or liquid fuels (**biofuels**). Biogas is produced in "digesters," tanks that are filled with sewage sludge, manure, and other organic wastes. Because the tanks do not allow oxygen to enter, the waste material inside undergoes anaerobic decomposition, producing a gas that is mostly methane (the major component of natural gas). Small-scale biogas digesters are a common feature on farms in China, India, and other developing countries, although the potential for large-scale biogas production in places like the United States is great. Biogas production is another of those win-win-win technologies since it addresses a waste problem (from sewage sludge and animal manure), generates useful energy in the form of biogas, and produces a residual sludge that makes excellent fertilizer.



Bigpra/iStock/Getty Images Plus

Biofuels are liquid fuels derived from organic materials such as plants. Biodiesel is derived from plant oils or animal fats.

Biofuels are the most widespread form of bioenergy, and the most common form of biofuel is ethanol. Ethanol is produced by fermenting carbohydrate-rich crops like corn and sugarcane. Brazil is a world leader in ethanol production and meets about 50% of its fuel needs for cars and light trucks with this biofuel. Virtually all the ethanol production in Brazil comes from sugarcane. Some cars in Brazil are modified to run entirely on ethanol, while others make use of a blended fuel that is 75% gasoline and 25% ethanol. The United States is actually the leading global producer of ethanol, mostly from corn, and ethanol accounts for about 10% of motor vehicle fuel consumption in this country. Most ethanol used in the United States comes in the form of a blended fuel known as E10 that is 90% gasoline and 10% ethanol. Together, the United States and Brazil produce 85% of the world's ethanol.

Another kind of biofuel is known as biodiesel. **Biodiesel** can be produced from plant oils and animal fats and burned in diesel automobile and truck engines. The most common "feedstock" for biodiesel production is soybeans, although canola oil, palm oil, coconut oil, and even waste cooking oil from fast-food restaurants can be used to produce this fuel. Similar to ethanol, biodiesel is typically used in a blend of 80% diesel and 20% biodiesel. Biodiesel use worldwide is only about half that of ethanol, with European countries making far greater use of this fuel than other regions.

Advantages and Disadvantages

Because bioenergy comes in so many different forms and is derived from so many different types of material, it is not as straightforward to assess the environmental and economic advantages and disadvantages of this energy source. One obvious advantage of bioenergy is that it is abundant and can be produced from so many different forms of organic material, much of which goes unused or is wasted each year. Another advantage is that biofuels can be used in existing internal combustion engines—unlike solar or wind energy, which can only power our transportation system if we convert to EVs.

Overall, one of the main theoretical benefits of all forms of bioenergy is that it has the potential to be a "carbon-neutral" form of energy. When firewood, agricultural waste, biogas, or biofuels are combusted, they do release the greenhouse gas carbon dioxide. However, the carbon in biomass and biofuels got there in the first place through photosynthesis, so presumably the same amount of carbon released during combustion is "recaptured" when new trees or crops are grown to replace the ones being burned or converted to biofuels. In reality it's not always as straightforward as this. For example, when wood from mature forests is burned, it releases carbon that has been stored for decades or even centuries, and new forest growth will take a long time to offset those emissions.

A related problem with biofuels, especially ethanol, has to do with the "net energy" gains from using these fuels. Recall that EROI is the amount of useful energy extracted from a resource divided by the amount of energy it took to produce it. It turns out that a significant amount of fossil fuel energy is utilized to plant and harvest some of the crops used for ethanol, and then again in the fermentation process used to convert those crops into ethanol fuel. Some studies have estimated that burning corn ethanol might actually result in *even greater* carbon dioxide emissions than just burning regular gasoline in the first place (Murphy, 2010). Other research suggests that using corn ethanol does reduce carbon dioxide emissions in the transportation sector but only by small amounts (Murphy, 2010). Sugarcane is a far less energy-intensive crop, and therefore sugarcane ethanol is better from a carbon dioxide standpoint and has a significantly higher EROI than corn ethanol.

Another disadvantage with biofuels has to do with a variety of land-use impacts. As discussed in Chapter 4, growing crops like corn on large-scale monoculture farms can have significant environmental effects in terms of soil erosion, water pollution, and downstream impacts like eutrophication and dead zones. Growing substantially more corn to produce relatively modest amounts of biofuel therefore does not seem to make a lot of sense. However, U.S. farm policy designed to help corn farmers has resulted in government mandates on ethanol production, and as much as 40% of the corn grown in the United States already goes to produce ethanol. Even if we were to allocate 100% of U.S. corn production to ethanol, it would still only produce about 25% of our transportation fuel needs; the same amount of fuel could be saved by simply improving automobile fuel efficiency by just 4 mpg (Conca, 2014). Meanwhile, shifting more corn production to ethanol creates ripple effects in other markets, since corn is also used to produce food for human consumption, sweeteners, and animal feed. Likewise, growing more soybeans, canola, coconuts, or palm for biodiesel production can also have land-use and environmental impacts at the farm level. We learned in Chapter 1 about the impacts on tropical forests from the expansion of palm oil production. Some of the expansion of palm oil in places like Southeast Asia is being driven by increased demand for biodiesel in Europe. As a result, we need to consider the ways in which biofuel production might be reliant on crops that are either better used for food consumption or have significant and negative environmental and land-use impacts.

Two other methods for producing biofuels appear to offer a number of advantages over current approaches. Unlike regular corn ethanol, for example, which is derived from the kernels or "food" portion of the corn plant, **cellulosic ethanol** is made from fermenting a variety of less useful plant parts and material like corn stalks and grasses. Cellulosic ethanol production can be based on agricultural waste products and grasses grown to reclaim abandoned farmland, and therefore it does not have the same negative environmental and land-use impacts. It also has a much higher EROI than regular ethanol and is far better in terms of net greenhouse gas emissions. The main challenge with cellulosic ethanol is developing enzymes that can break down the tougher plant material—cellulose—found in stalks and grasses. Likewise, there is growing interest in producing biodiesel and/or ethanol from algae. Algae is fast growing and can be modified to grow in open ponds or even in vertical tubes and tanks in urban settings.

Overall, various forms of bioenergy will continue to play a major role in the global energy economy for the foreseeable future. Current usage of corn-based ethanol in places like the United States appears to be based far more on political considerations and farm support programs than on any environmental or economic logic. Therefore, it would seem wise to begin to shift some of the resources and focus from current approaches to newer and less destructive forms of bioenergy. Biogas production from municipal sewage and animal feedlots, cellulosic ethanol, sustainably produced wood energy, and algae-based biodiesel production are all examples of such approaches.

7.12 Hydropower, Geothermal Energy, and Ocean Energy

Decades before modern solar panels and wind turbines were developed, we used the energy contained in running water and from under the Earth's surface. **Hydroelectric power** (**hydropower**) harnesses the kinetic energy of moving water to generate electricity. For well over a century, dams have been built to exploit this energy resource. **Geothermal power** makes use of heated water from deep underground reservoirs to produce steam to generate electricity. More recently, geothermal applications have been expanded to take advantage of the near constant temperatures found just underneath the Earth's surface to heat and cool buildings. In addition, there is growing interest in exploiting the energy found in the waves and tides, known as **ocean energy**. Because the water cycle keeps water constantly moving, and because the processes that produce geothermal, tidal, and wave energy will continue to do so indefinitely, these forms of energy are also considered renewable.

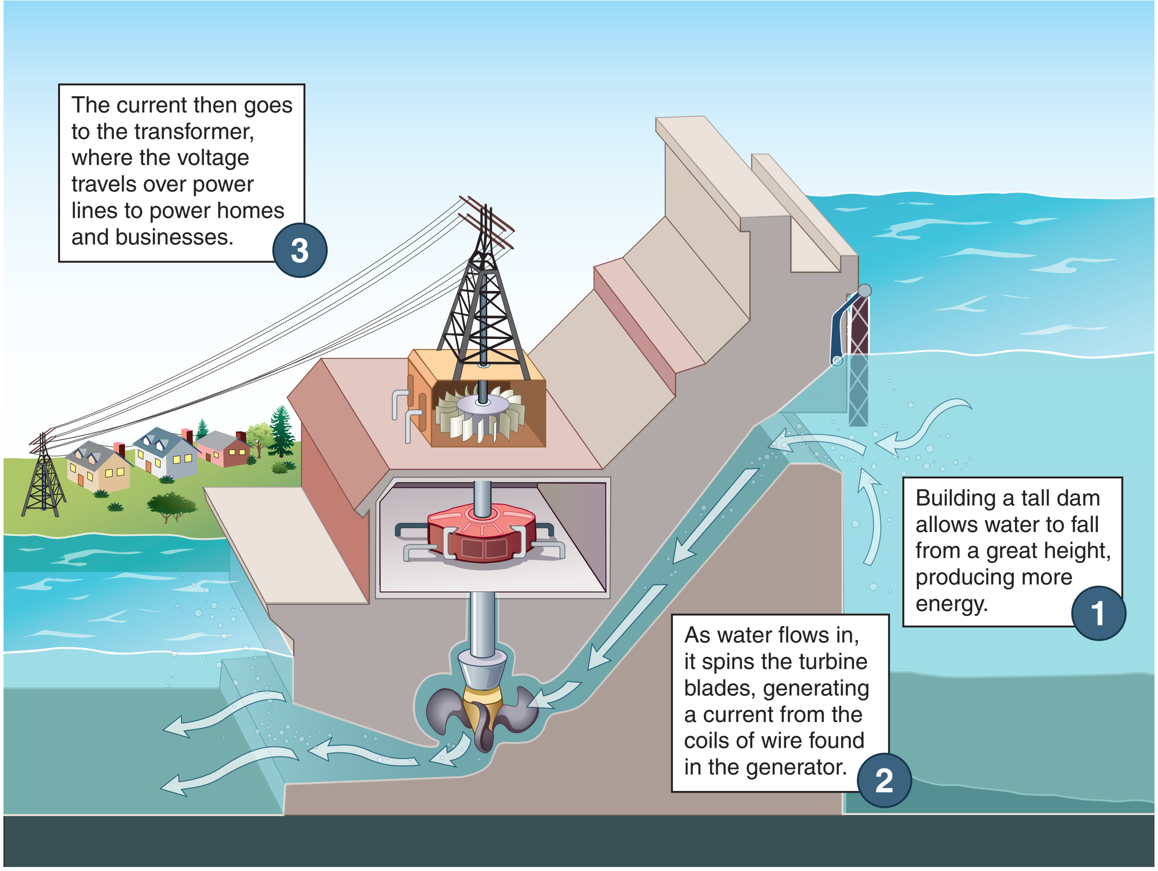
Hydropower

The most common form of hydropower is known as an **impoundment hydroelectric plant**. This involves building a dam across a river to store or "impound" water behind the dam in a reservoir (see Figure 7.7). When water is released through openings in the dam, it flows downhill to where a turbine is located. The kinetic energy of the moving water spins the turbine to generate electricity. A less common approach to hydropower is to divert a portion of flowing water from a river to a hydroelectric plant (without using a dam), a technique known as **run-of-river hydropower**. Hydropower currently meets 16% of global electricity demand, with China, Brazil, Canada, and the United States as the largest producers. Hydropower accounts for nearly 100% of electricity production in some countries, like Norway and Paraguay, while meeting over 60% of Brazil's and 50% of Canada's electricity demand. Hydropower accounts for 7% of electricity generation in the United States.

The main advantage of hydropower is that it generates electricity without fossil fuel combustion, so there are no direct emissions of air pollutants or greenhouse gases. However, because hydropower usually involves the construction of a dam to create a reservoir, it can have a number of ecological and social impacts. These include the destruction of wildlife habitat as well as modifications to river flow patterns. This can impact water temperature and water quality, disrupt fish migration patterns, and alter downstream ecosystems that have evolved over time to specific river flow patterns. Furthermore, large hydroelectric reservoirs in tropical regions have been linked to increased methane emissions, canceling out some of the benefits of reduced CO_2 emissions (Hurtado, 2016). In this sense it might be fair to say that hydropower is renewable but not necessarily sustainable. Because many of the best sites for hydropower development have already been exploited, and because large dam projects can generate significant public opposition, it's not likely that hydropower production will increase in the future at the same rates as solar and wind energy.

Figure 7.7: Hydroelectric dam

An impoundment hydroelectric dam converts the kinetic energy of the falling water into electricity.



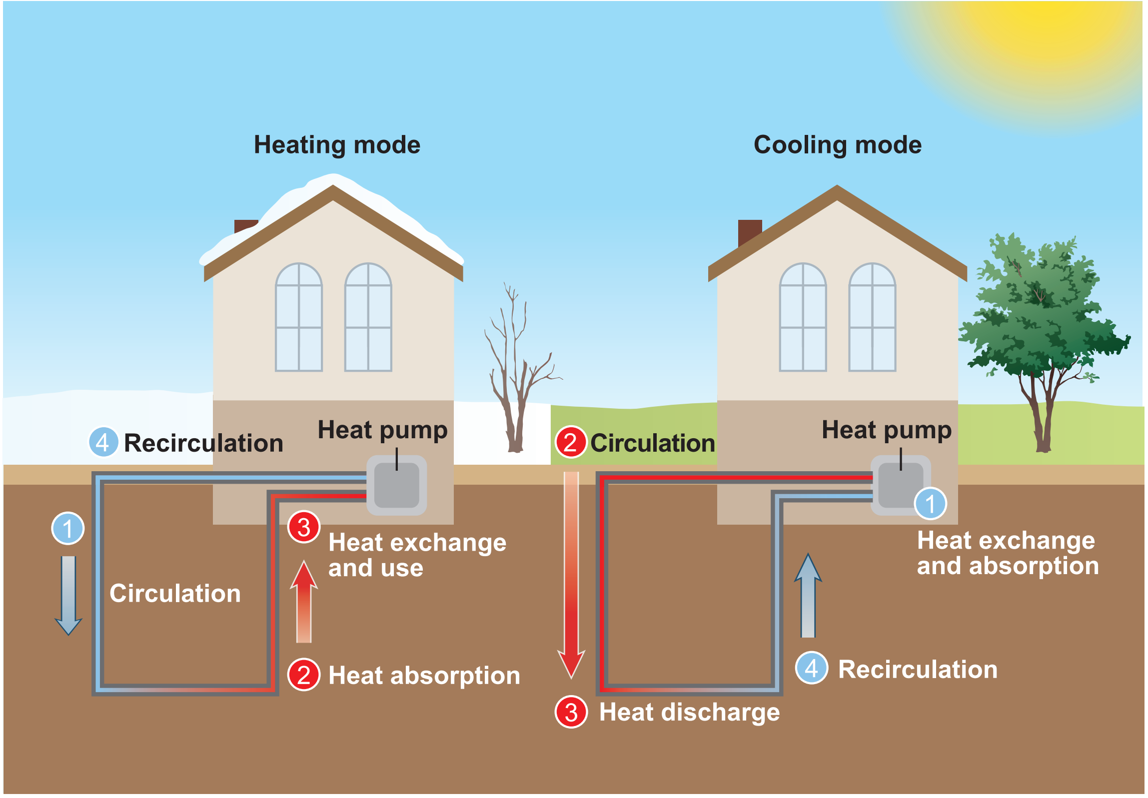
Geothermal Energy

Geothermal energy resources can be used in large-scale power plants to produce electricity or at a smaller scale to heat and cool homes and other buildings. Geothermal power plants utilize steam from hot water reservoirs found miles below the Earth's surface to spin a turbine and generate electricity. These types of power plants are very location specific, since they rely on certain geologic conditions that allow hot magma from deep within the Earth's interior to flow near enough to the surface to heat water. The top geothermal power producers in the world are the United States, the Philippines, Indonesia, Mexico, and New Zealand.

A different form of geothermal energy that is not as location specific is known as ground-source heating and cooling, or **ground-source heat pumps (GSHPs)**. GSHPs operate on the very basic principle that the ground just 2 to 3 meters (6 to 10 feet) below the surface maintains a fairly constant, year-round temperature of 10 °C to 15 °C (50 °F to 60 °F). In temperate regions with changing seasons, this ground temperature is warmer than outside air in the winter months and cooler than outside air during summer months. GSHP systems use a heat pump and a series of underground plastic pipes to circulate water or another fluid between a building and the underground space around that building (see Figure 7.8). In the summer months the water or fluid in those pipes transfers warm air from the building underground to be cooled and brought back into the building. In the winter months it does the opposite, transferring heat from underground into the building. There are already well over 1 million GSHP systems installed in homes, schools, hospitals, and other buildings in the United States, and another 60,000 to 80,000 new systems are added each year.

Figure 7.8: Ground-source heat pump

GSHPs circulate water or another fluid through a series of underground pipes to heat air in the winter and cool air in the summer.



*Source: Adapted from "Geothermal Heating and Cooling Technologies," by US Environmental Protection Agency, 2016 (**https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies**).*

Both geothermal power and ground-source heating/cooling systems help reduce air pollution and greenhouse gas emissions. They both also have fairly minimal environmental impacts, although construction of large-scale geothermal power plant complexes can be disruptive to local ecosystems. Unlike with hydropower, there is still a fair amount of untapped geothermal power potential to be developed in those regions of the world with favorable conditions. Likewise, demand for GSHP systems continues to remain strong, even if installing these systems in homes encounters the same up-front cost problem associated with residential PV systems.

Ocean Energy

The two main approaches to harnessing the energy of the oceans is to exploit the kinetic energy of the tides (**tidal power**) and the waves (**wave power**).

Tidal power can be harnessed in a few different ways. A *tidal barrage* is basically a dam that is constructed across the mouth of a tidal basin. As the tide rises, the gates of the barrage are opened to allow water in, and at high tide the gates are closed to impound that water behind it. After the water on the other side drops during low tide, the barrage gates are opened again to release the water that's impounded and generate electricity through spinning turbines. A *tidal fence*, which resembles a turnstile, is placed underwater in narrow channels, where tidal currents spin the blades to produce electricity. Likewise, *tidal turbines* operate like underwater wind turbines, except that their blades are spun by tidal currents rather than the wind.

Wave power systems are either offshore or onshore. Offshore wave power systems rely on the bobbing, up-and-down motion of waves to power a pump that generates electricity. Onshore wave energy systems are built along the coastline and are powered by the energy of breaking waves. This is typically accomplished by constructing a chamber filled with air and open to the sea. As waves enter the chamber, they push the air past a turbine, which spins to produce electricity.

Ocean energy systems are clean and renewable. However, tidal barrage systems are only viable in a small number of places around the world with the right combination of geography and tidal swings. Tidal fence and turbine systems can be located in a larger number of geographic locations, but they can be costly to build and maintain and are challenging from an engineering standpoint. Wave power systems are also still mostly experimental, given some of the technical and engineering issues facing large-scale deployment of these technologies.

7.13 Energy Markets and Policies

What investments in energy efficiency and renewable energy sources have in common is that they represent what could be called a “no-regrets” or “win-win-win” approach to energy policy. Even if we took the issue of global climate change out of the picture, energy efficiency and renewable energy are good for our economy, enhance national security, and help address known and immediate environmental problems like air and water pollution. (The *Apply Your Knowledge* feature explores how to determine which energy option is best.)

Overall, the renewable energy approaches and technologies described in this chapter offer the two main advantages of being clean and virtually inexhaustible and renewable. Some of these technologies are experiencing rapid growth and are already making major contributions to meeting our energy needs. Others have more limited potential for geographic, geological, or engineering reasons, but they can play an important part in meeting localized energy demand. The fact that we are not undergoing an even more rapid energy transition despite these advantages and win-win-win outcomes has much to do with energy policy and politics in our country and around the world.

Apply Your Knowledge: Which Energy Option Is Best?

Some experts believe we should invest in zero-carbon energy sources like wind, solar, and nuclear, while others promote more energy-efficient buildings and transportation systems. It can be hard to tell which technologies would be best for the environment, especially when you try to consider the economic costs of different solutions. Fortunately, we can use some math to compare options and prioritize the most effective technologies.

To begin our analysis, let us first compare the environmental benefits of different technologies using a common metric. In this exercise, we will measure environmental benefits using the amount of CO_2 emissions that are avoided by implementing different technologies. For example, putting a moderate-sized solar panel system on your roof might prevent local power plants from releasing the equivalent of 20 metric tons of CO_2 into the atmosphere over the course of that system's lifetime.

To help us consider the economics of different options, we consider the costs and savings associated with each technology. Your rooftop solar system would cost a certain amount of money to install and maintain, but it would also save you money on electricity. Depending on the specific costs and savings at a particular location, the overall system might gain or lose money over the course of its lifetime. In this activity, we will consider the net costs (the total costs minus the total savings) of implementing different technologies.

To take our analysis one step further, we can divide the net costs by our emissions reductions to estimate the cost of avoiding 1 metric ton of CO_2. This final value is called an *abatement cost*. When it is a positive value, it means that it will cost money to avoid 1 metric ton of CO_2. When it is a negative value, money is being saved.

Now that we have a good metric for comparing sustainable energy solutions, let us take a look at some data in what is called an *abatement curve*. In Figure 7.9, various energy technologies are represented as rectangles stacked side by side along the x-axis. The rectangle widths represent the average annual emissions reductions that could be achieved by these technologies in the United States. The rectangle heights represent the estimated abatement costs of these measures if they were to be implemented before the year 2030. Based on this information, what energy measures and technologies do you think the United States should prioritize going forward?

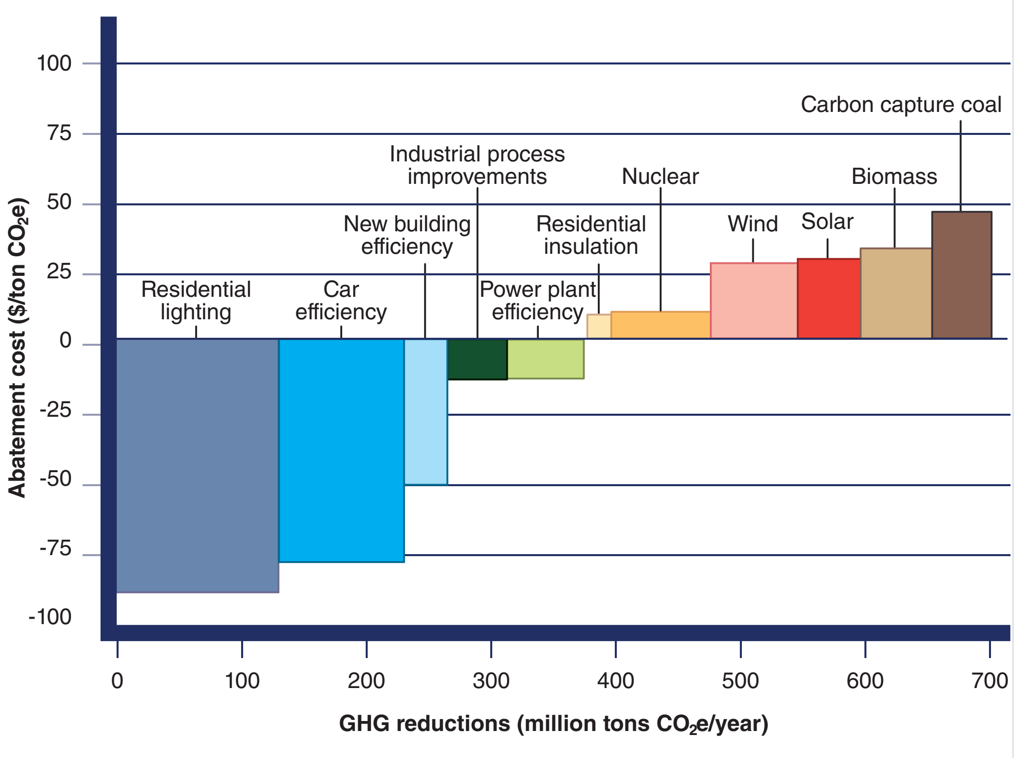
We can learn a lot of valuable information when we look at abatement curves like Figure 7.9. For one thing, we can see that energy efficiency measures are generally more cost effective than replacing existing power plants. This helps illustrate that even if certain technologies receive a lot of media attention, they may not necessarily be the most cost effective ways to increase sustainability. Figure 7.9 also shows that there are several options with negative abatement costs. These options are mostly energy efficiency measures, and the numbers suggest that they will actually save money over time. Energy efficiency represents a win-win in terms of cost and emissions, and it is a great place to start when planning and implementing better energy systems.

(continued)

Apply Your Knowledge: Which Energy Option Is Best? *(continued)*

Figure 7.9: 2030 U.S. abatement curve

Abatement costs of greenhouse gas (GHG) reductions measures. The width of the rectangles shows estimated average annual emissions reductions of each measure. The height of the rectangles and their position along the y-axis shows the projected cost of the measure if implemented before 2030. "CO_2e" refers to carbon dioxide equivalents, which allows us to consider all greenhouse gases in this discussion.



Source: Adapted from Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? *by McKinsey and Company, 2007, p. 42 (**https://www.mckinsey.com/business-functions/sustainability/our-insights/reducing-us-greenhouse-gas-emissions**).*

Decisions that individuals and businesses make about how much and what types of energy to use are shaped in large part by the prices of different energy sources. In a perfectly free market, those energy prices would reflect the true cost of what it takes to develop, distribute, and utilize a specific energy resource. In reality, energy markets in the United States and around the world are far from free and are influenced and shaped by government policies. For example, the Organisation for Economic Co-operation and Development estimates that worldwide government subsidies to fossil fuel companies were as high as $373 billion in 2015 (Timperley, 2018). The International Monetary Fund, using a broader definition of subsidies, put this figure at close to $5 trillion in that year (Coady, Parry, Le, & Shang, 2019). Regardless, subsidies help artificially reduce the price of the energy resource being subsidized.

When you combine government intervention with a consideration of external costs—those costs associated with the use of an energy resource but not factored into market price—you end up with fossil fuel energy prices that are significantly lower than what they actually cost society. This is because taxpayers pay for the subsidies, and we all eventually pay for the external costs. These artificially low fossil fuel prices *distort* decision making by consumers and businesses, inflate demand for fossil fuels, and make renewable energy alternatives appear more expensive and less competitive than they actually are.

Given the clear environmental, economic, and social benefits associated with shifting from an overreliance on fossil fuels to greater use of clean, renewable energy sources, how can government policy be altered to speed up the energy transition? Energy economists offer a number of possible suggestions.

Full-Cost Pricing

Full-cost pricing of energy refers to “internalizing” the external costs associated with the use of a particular energy resource. For example, if you live in an area that relies mainly on coal for electricity generation, it is almost certain that you are not currently paying the full cost for that electricity. As discussed earlier in the chapter, coal mining destroys habitats and causes serious water pollution problems, while coal combustion results in local/regional air pollution and greenhouse gas emissions. These environmental impact costs are not, for the most part, factored into the price that power companies pay for coal or that consumers pay for electricity produced with that coal. This makes coal and coal-fired electricity appear cheaper than they actually are and distorts our decisions in the process.

One way to achieve full-cost pricing in this case would be to impose an energy tax or **carbon tax** on coal in an amount that would reflect some of these external costs. Revenue from that tax could be used to restore habitat damaged by coal mining, clean water supplies polluted by mining, fund health care in places polluted by coal combustion, or offset higher electricity costs for low-income consumers.

Subsidy Reform

Subsidy reform refers to diverting subsidies to cleaner energy resources. Historically, fossil fuels and nuclear power have received far more in the way of U.S. government subsidies and tax breaks than renewable energy sources. One study estimated that from 1918 to 2009, the oil and gas industry received close to $500 billion in subsidies and tax breaks, while the figure for nuclear power was nearly $200 billion (Pfund & Healey, 2011). Most subsidies to renewable energy came in the form of funding ($30 billion) for biofuels, a policy that as mentioned earlier has less to do with energy and more to do with farm support. Under $6 billion in subsidies and tax breaks went to renewable energy sources like wind and solar during that time period. This situation has begun to change as more focus has been put on renewable energy sources in recent years. Given that one of the main policy goals of subsidies should be to speed up the development and deployment of *new* and *innovative* technologies, focusing the bulk of government funding and tax breaks on long-established energy sources like oil, coal, and nuclear power might not make the most sense.

Feed-In Tariffs

Feed-in tariffs require electric power companies to buy electricity at a guaranteed price from any individual or business that can generate it and "feed" that electricity back into the power grid. For example, home owners and businesses can install a PV system on their roof knowing that any electricity generated by that system will be purchased by the power company. This makes it much easier to acquire bank financing for the up-front cost of installing such a system, since the revenue from the electricity sales can be used to pay off the loan. After that, home owners and businesses can actually meet their own electricity needs while also profiting from the sale of any excess electricity. As a result of a feed-in tariff policy, solar and wind power installations have skyrocketed in Germany and made that country a world leader in renewable energy adoption.

Renewable Portfolio Standard

A **renewable portfolio standard (RPS)** is simply a government mandate (city, state, or federal) that a certain percentage of energy use in that location come from renewable energy sources. In the United States 38 states have some sort of RPS in place, and dozens of cities ranging in size from New York to Reno have also adopted an RPS. RPS mandates create increased demand for renewable energy sources and create incentives for private investors to finance these technologies. Even without RPS mandates, there was already a clear trend of *private* venture capital moving increasingly toward renewable energy investment. In 2016 it's estimated that private investors accounted for 92% of the $263 billion that was invested in renewable energy that year (International Renewable Energy Agency, 2018).

Other Approaches

Beyond full-cost pricing, subsidy reform, feed-in tariffs, and renewable portfolio standards, there are a handful of other policy approaches that can help speed up the energy transition. These include supply-side approaches aimed at increasing the amount of renewable energy being generated, like research and development funding, tax credits for renewable energy production, and tax credits to home owners and businesses that install solar PV panels or GSHPs. There are also demand-side approaches to reduce energy consumption and improve efficiency. These include increasing fuel efficiency standards in cars, promoting more efficient appliances, and providing tax credits to home owners to insulate their homes and improve energy efficiency. What all these policies have in common is that they create a market environment that is more favorable to renewable energy sources than has historically been the case. While free-market advocates may argue against such an approach, the reality is that our energy markets are already distorted and influenced by government tax and regulatory policies. Those tax and regulatory policies favor the continued use of fossil fuels and ignore many of the negative environmental, economic, and social impacts of using these fuels. What is needed is a new policy approach that recognizes the critical need to move toward a greater reliance on renewable energy sources.

Bringing It All Together

In 2011 energy experts Mark Jacobson of Stanford University and Mark Delucchi of the University of California–Davis published a comprehensive, two-part paper on whether it was possible and what it would take to move the world to 100% reliance on renewable energy sources by the year 2050 (Jacobson & Delucchi, 2011a, 2011b). Jacobson and Delucchi examined issues of technology, geography, energy markets and economics, energy storage and distribution systems, and political and cultural barriers to change and concluded that a transition to 100% renewable in the next few decades was possible. Their overall conclusion was not only that such a shift was technically possible but that it could actually result in improved economic conditions as well.

While not all energy experts agree with the assumptions or conclusions reached by Jacobson and Delucchi, their research has generated an interesting discussion about our energy future. Our current reliance on fossil fuel energy sources is both environmentally destructive and unsustainable, given the limited and finite supplies of these energy sources. While renewable energy technologies like wind and solar energy still only account for a small percentage of our energy supply, they are technically and economically viable and poised for continued rates of rapid growth. We must speed up the transition away from fossil fuels and toward renewable energy sources to mitigate the impacts on air quality and climate change. Those impacts, and the urgency of the situation, are the focus of the next chapter.

Additional Resources

Our Energy System

In addition to the EPA Power Profiler introduced in the *Close to Home* feature box, the *New York Times* has an interesting interactive feature that allows you to see how the electricity used in your state is produced and how that has changed over time.

- https://www.nytimes.com/interactive/2018/12/24/climate/how-electricity-generation-changed-in-your-state.html

The EIA has a good page explaining how electricity is produced and distributed to end users.

- https://www.eia.gov/energyexplained/index.php?page=electricity_generating

Natural Gas

Natural gas has been hailed as an “energy bridge to the future” because of its relatively low CO_2 emissions relative to coal. The idea is that we can use more natural gas instead of coal in order to allow time for renewable energy sources like wind and solar to be more fully developed. However, this claim only focuses on CO_2 emissions from natural gas, whereas a recent study in *Science* of natural gas production and distribution systems found large emissions of methane (another greenhouse gas) from this energy source (Alvarez et al., 2018). The first link summarizes the findings; the second link is to the journal article itself.

- https://insideclimatenews.org/news/21062018/methane-leaks-oil-gas-climate-change-risks-natural-gas-slcp-global-warming-pollution-science-edf-study
- https://www.edf.org/media/new-study-finds-us-oil-and-gas-methane-emissions-are-60-percent-higher-epa-reports-0

Nuclear Energy

Nuclear power can seem like a challenging concept to grasp, but the basic idea behind it is quite simple. These sources help explain how electricity is produced through nuclear fission reactions.

- https://www.ucsusa.org/nuclear-power/nuclear-power-technology/how-nuclear-power-works
- https://www.nei.org/fundamentals/how-a-nuclear-reactor-works
- https://www.energy.gov/ne/articles/nuclear-101-how-does-nuclear-reactor-work

The debate over the prospects for nuclear power and whether it has role to play in meeting future energy needs has really heated up in recent years. These sources present both sides of the argument.

- https://e360.yale.edu/features/why-nuclear-power-must-be-part-of-the-energy-solution-environmentalists-climate
- https://e360.yale.edu/features/industry-meltdown-is-era-of-nuclear-power-coming-to-an-end
- https://www.washingtonpost.com/outlook/i-oversaw-the-us-nuclear-power-industry-now-i-think-it-should-be-banned/2019/05/16/a3b8be52-71db-11e9-9eb4-0828f5389013_story.html

Solar Energy

Solar energy can be used for illumination, heating, and producing electricity (solar power). These sources help explain how some of the technologies that make solar energy possible actually work.

- https://www.energy.gov/science-innovation/energy-sources/renewable-energy/solar
- https://www.energy.gov/eere/solar/articles/solar-energy-technology-basics
- https://www.energy.gov/eere/solar/downloads/solar-power-basics
- https://www.ucsusa.org/clean-energy/renewable-energy/how-solar-energy-works

Wind Energy

These sources help explain how wind power works and how a wind turbine is designed to convert the energy in wind into electricity.

- https://www.energy.gov/eere/wind/how-do-wind-turbines-work
- https://www.energy.gov/videos/energy-101-wind-turbines
- https://www.energy.gov/maps/how-does-wind-turbine-work
- https://www.ucsusa.org/clean-energy/renewable-energy/how-wind-energy-works

Geothermal Energy

These two sources help explain the basics behind large-scale geothermal power systems as well as smaller scale ground-source heat pumps.

- https://www.energy.gov/eere/videos/energy-101-geothermal-energy
- https://www.energy.gov/eere/videos/energy-101-geothermal-heat-pumps

The Energy Transition

April 2019 was a milestone month for renewable energy in the United States. This was the first month in which, collectively, renewable energy sources like hydropower, solar energy, and wind power produced more energy than coal. This is further evidence of the energy transition that is under way in the United States and around the world. You can learn more about this event at these sites.

- https://grist.org/article/renewable-energy-outpaced-coal-in-april-for-the-first-time-ever
- https://www.forbes.com/sites/andystone/2019/06/30/as-clean-energy-surpasses-coal-us-energy-transition-locks-into-place/#1ec0ba8a2ef7

Energy Efficiency and Conservation

Zero-energy homes and buildings are structures that produce as much energy as they consume. These sources help explain the basics behind the zero-energy concept.

- https://www.energy.gov/eere/buildings/zero-energy-buildings
- https://zeroenergyproject.org/buy/zero-energy-homes

Energy justice initiatives are occurring all over the nation, as these articles discuss.

- https://e360.yale.edu/features/energy-equity-bringing-solar-power-to-low-income-communities
- https://grist.org/article/pueblo-colorado-renewable-energy-future

Renewable Portfolio Standards

Renewable portfolio standards are one way to promote greater use of renewable energy sources. You can learn more about RPS programs and whether your state has an RPS at these sites.

- http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx
- https://www.seia.org/initiatives/renewable-energy-standards
- http://eta-publications.lbl.gov/sites/default/files/2018_annual_rps_summary_report.pdf

Key Terms

active solar energy The use of mechanical and electrical equipment to convert sunlight to heat and electric power.

biodiesel A biofuel made from plant oils and animal fats.

bioenergy Energy derived from living, organic material. Also known as *biomass energy*.

biofuels Liquid fuels derived from biomass.

biogas Gaseous fuel derived from biomass.

biomass energy See *bioenergy*.

carbon capture and storage (CCS) Approaches intended to capture carbon dioxide emissions from coal burning, convert them into liquid, and pump the liquid underground for long-term storage.

carbon sequestration See *carbon capture and storage (CCS)*.

carbon tax A tax or fee on carbon-based fuels (coal, oil, and natural gas) that is intended to reduce carbon emissions.

cellulosic ethanol A biofuel made from grasses or the less useful parts of a plant, such as the stalks and leaves.

clean coal technology Approaches designed to remove contaminants from coal before it is burned.

coal seams Layers of coal.

concentrating solar power (CSP) systems Large-scale complexes that generate solar power using mirrors to concentrate the sun's rays on a tank or series of pipes filled with water or another fluid.

conventional deposits Sources of fossil fuels that can be accessed using traditional drilling or mining techniques.

crude oil Unrefined oil that has just been extracted from the ground before being sent to an oil refinery.

energy conservation The reduction of energy consumption through changes in behavior.

energy conversion The process of changing one form of energy into another.

energy conversion efficiency The percentage of primary energy converted to secondary energy.

energy efficiency The process of using less energy to achieve the same outcome.

energy end-use efficiency The percentage of primary energy used in its final destination.

energy return on investment (EROI) The amount of useful energy extracted from a resource divided by the amount of energy it took to produce that energy.

energy transition A transformation of energy systems.

feed-in tariff A program whereby energy producers are paid for the electricity they send to the grid.

fossil fuels Fuels formed from the remains of organisms over millions of years.

fracking See *hydraulic fracturing*.

geothermal power Power derived from heated water from deep underground reservoirs.

ground-source heat pump (GSHP) A heating and cooling system that transfers heat to or from the ground.

hydraulic fracturing A technique for removing oil and natural gas from shale deposits; it involves pumping a liquid–sand mixture into deposits in order to crack the shale open so oil and gas can flow. Also known as *fracking*.

hydroelectric power Power derived from the kinetic energy of moving water. Also called *hydropower*.

hydropower See *hydroelectric power*.

impoundment hydroelectric plant A power plant that generates electricity by releasing water from a dam.

mountaintop removal mining A form of strip mining that involves removing the top portion of a mountain to expose the coal underneath and dumping the material (overburden) into surrounding valleys.

nonrenewable energy Fossil fuels; energy sources that, once consumed, are no longer available.

nuclear chain reaction A series of nuclear fissions that releases a large amount of energy.

nuclear energy See *nuclear power*.

nuclear fission The reaction that occurs when the nucleus of an atom is split to form two smaller nuclei, releasing energy in the process.

nuclear power Electricity produced through a nuclear reaction.

nuclear reactors Devices used by nuclear power plants to initiate and control nuclear fission.

ocean energy The energy found in waves and tides.

oil refineries Distillation plants where crude oil is broken down into different products.

oil reservoirs Porous rock formations that hold small drops of oil in their pores.

oil sands Formations found near the surface that contain a tar-like substance known as bitumen, which can be refined into oil. Also known as *tar sands*.

oil shale A rock formation that holds oil and gas but is not porous enough to allow movement of oil or gas through it.

passive solar energy The use of sunlight directly, without mechanical devices, to illuminate or heat interior spaces.

peak oil The point in time when global oil production and use reaches its highest point before beginning a period of permanent decline.

photovoltaic (PV) cells Devices that convert sunlight into electricity.

primary energy Energy that is stored in natural resources.

primary oil recovery The initial process extracting oil through natural pressure.

proven reserves The quantities of an energy source that can be extracted from known deposits, using current technology, at current prices.

renewable energy Energy sources that are replenished in a human timescale.

renewable portfolio standard (RPS) A government mandate that a certain percentage of energy use come from renewable energy sources.

reserves-to-production (R/P) ratio A measure of how long a resource will last.

run-of-river hydropower A power plant that generates electricity by diverting water from a river.

secondary energy Energy that is converted from primary energy into a more useful form.

secondary oil recovery The process of extracting oil once primary oil recovery methods are exhausted, including injecting fluids into a reservoir to increase pressure.

solar energy Energy from the sun.

solar power The use of solar energy to generate electric power.

strip mining See *surface mining*.

subsurface mining See *underground mining*.

surface mining The process of using giant earth-moving machines to scrape away vegetation, topsoil, and rock to reveal a shallow coal seam. Also known as *strip mining*.

tar sands See *oil sands*.

tertiary oil recovery The process of extracting oil once secondary oil recovery methods are exhausted, including injecting heated fluids or gases into a reservoir to increase pressure even further.

tidal power The power derived from the kinetic energy of the ocean tides.

unconventional deposits Sources of fossil fuels that cannot be accessed using traditional methods.

underground mining The process of digging tunnels or shafts into the ground to reach coal seams that are deeper than 60 meters (200 feet). Also known as *subsurface mining*.

wave power The power derived from the kinetic energy of the ocean waves.

wind power The power derived from the kinetic energy of the wind.

wind turbines Large mechanical assemblies that convert the wind's kinetic energy into electrical energy.