Chapter 4
Alternative Energy

Learning Outcomes

By the end of this chapter, students will be able to:

1. Describe arguments for alternative energy.
2. Explain the following aspects of solar energy:
   a. How passive solar energy works and provide examples of its use.
   b. How solar panels (photovoltaic cells) work.
   c. The limitations and environmental costs associated with solar energy.
3. Describe wind energy, and explain its advantages and disadvantages.
4. Describe hydroelectric energy, and explain its advantages and disadvantages.
5. Describe geothermal energy and explain the advantages and disadvantages.

6. Explain the following aspects of biofuels / biomass energy:
   a. Describe what is meant by the term “carbon neutral” and explain how biomass energy can and cannot be carbon neutral.
   b. Describe current achievements in biofuels and potential of this area for growth.

Chapter Outline

LEARNING OUTCOMES .....................................................................................................................1

4.1 WHAT IS RENEWABLE ENERGY? ..........................................................................................3
   4.1.1 THE WORLD’S GROWING ENERGY NEEDS ..............................................................5
   4.1.2 WHY USE RENEWABLE ENERGY SOURCES? .......................................................7

4.2 SOLAR ENERGY ......................................................................................................................7
   4.2.1 PASSIVE AND ACTIVE SOLAR POWER ..................................................................8
       PHOTOVOLTAIC (PV) CELLS ..................................................................................9
       SOLAR THERMAL COLLECTORS .......................................................................10
       SOLAR THERMAL SYSTEMS ............................................................................11
   4.2.2 ENVIRONMENTAL IMPACTS OF SOLAR ENERGY ...............................................12

4.3 WIND POWER .......................................................................................................................12
   4.3.1 ENVIRONMENTAL IMPACTS OF WIND POWER ..................................................13

4.4 HYDROELECTRIC POWER ....................................................................................................14
   4.4.1 STORAGE HYDROPOWER ..................................................................................15
   4.4.2 PUMPED-STORAGE HYDROPOWER ....................................................................17
   4.4.3 RUN-OF-RIVER HYDROPOWER ..........................................................................18
   4.4.4 ENVIRONMENTAL IMPACTS OF HYDROPOWER ................................................19
   4.4.5 POTENTIAL OF TIDAL POWER ...........................................................................20

4.5 GEOTHERMAL ENERGY .........................................................................................................21
   4.5.1 ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY ..................................22

4.6 BIOMASS ENERGY ..................................................................................................................25
   4.6.1 DIRECT COMBUSTION OF SOLID BIOMASS .......................................................26
   4.6.2 GASEOUS BIOMASS ............................................................................................28
   4.6.3 LIQUID BIOFUELS ...............................................................................................29
   4.6.4 ENVIRONMENTAL IMPACTS OF BIOMASS ENERGY .........................................30

4.7 OTHER RENEWABLE ENERGY SOURCES ........................................................................31
   4.7.1 HYDROGEN FUEL ...............................................................................................31
       HYDROGEN FUEL CELL VEHICLES ......................................................................32
       CHALLENGES OF HYDROGEN ...........................................................................33
   4.7.2 ELECTRIC AND HYBRID VEHICLES .....................................................................33

4.8 POLICY AND CONSERVATION ............................................................................................34
TEST YOUR UNDERSTANDING .....................................................................................................35
TERMS ..............................................................................................................................................36
4.1 What is Renewable Energy?

Energy sources that are more or less continuously made available within a timeframe useful to people are called renewable energy. Renewable energy sources are often considered alternative energy sources because, in general, most industrialized countries do not rely on them as their main energy source. Instead, they tend to rely on the conventional energy sources such as fossil fuels or nuclear power that are non-renewable. Because of the worldwide energy crisis of the 1970s, dwindling supplies of fossil fuels, and hazards associated with nuclear power, use of renewable energy sources such as solar energy, hydroelectric, wind, biomass, and geothermal has grown. Renewable energy comes from the sun (considered an "unlimited" or completely renewable supply) or other sources, such as biomass, that can theoretically be renewed at least as quickly as they are consumed (semi-renewable resources). If used at a sustainable rate, these sources will be available for consumption for thousands of years or longer. Renewable alternatives can be derived from wind, water, solar or biomass (Figure 4.1), to name a few. Some renewable energy sources are really indirect forms of solar energy, because energy from the sun was required to form these sources. Indirect solar energy sources include wind energy, biomass energy, and some forms of water-based energy. Limitations currently associated with most forms of renewable energy is that the energy include that they are not concentrated, not easily portable, and/or not easy to store.

Figure 4.1. A variety of voltage sources (clockwise from top left): the Brazos Wind Farm in Fluvanna, Texas (credit: Leaflet, Wikimedia Commons); the Krasnoyarsk Dam in Russia (credit: Alex Polezhaev); a solar farm (credit: U.S. Department of Energy); and a group of nickel metal hydride batteries (credit: Tiaa Monto). The voltage output of each depends on its construction and load, and equals emf only if there is no load.
Energy is an important ingredient in all phases of society. We live in global society, and access to adequate and reliable energy resources is crucial for economic growth and for maintaining the quality of our lives. However, current levels of energy consumption and production are not sustainable because of the heavy reliance on non-renewable energy sources, which will eventually become depleted. The principal energy resources used in the world are shown in Figure 4.2. The fuel mix has changed over the years but now is still dominated by fossil fuels. Over 30% of the world’s energy consumption comes from oil, and much of that goes to transportation uses. In 1973, almost 87% of the global energy consumed was from fossil fuels. Today, that value is closer to 80%. Even as the percentage of our energy

![Figure 4.2](https://www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf)

Figure 4.2. Total world energy consumption by source in 1973 and 2015. Total energy consumption (displayed inside teal boxes) is measured in units of Mtoe, or mega tonne of oil equivalent. 1 Mtoe = 11.63 megawatt-hours (MWh), 41.87 gigajoules (GJ), or 39.7 million British thermal units (Btu). Image from the 2017 Key World Energy Statistics publication by the International Energy Agency. https://www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf

domains of transportation, industry, and household use. Renewable energy sources, such as hydro, wind, solar, and biomass, are also important contributors to the global energy mix, offering sustainable alternatives to non-renewable resources.

In 1973, almost 87% of the global energy consumed was from fossil fuels. In 2015, that value has decreased to closer to 80%. As a global society, we consumed over twice as much energy in 2015 than we did in 1973. Energy sources that have grown include nuclear power, which,
though non-renewable, produces no **greenhouse gas** emissions, and renewable forms such as hydropower, geothermal, solar, wind, etc. As we continue to expand in our total energy usage, the utilization of renewable energy sources, particularly those that do not emit greenhouse gases, may be the key to limiting environmental impacts related to **global climate change** (see Chapter 6). Although presently only a small percentage, renewable energy is growing very fast, especially wind energy. For example, Germany plans to meet 20% of its electricity and 10% of its overall energy needs with renewable resources by the year 2020.

**4.1.1 The world’s growing energy needs**

World energy consumption continues, to rise especially in the **emerging economies** of China and India. Global demand for energy has grown rapidly over time (Figure 4.3). Much of this growth will come from the rapidly booming economies of China and India. Growth has slowed in many more-industrialized countries, especially those in Europe, where population sizes have stabilized or are shrinking (review this concept in Chapter 2). Energy is often a constraint in the rapid economic growth of China and India. In 2003, China surpassed Japan as the world’s second largest consumer of oil. However, over one third of this oil is imported. Unlike most Western countries, coal dominates the commercial energy resources of China, accounting for two thirds of its energy consumption. In 2009, China surpassed the United States as the largest emitter of CO₂. In India, the main energy resources are biomass (wood and dung) and coal. Half of India’s oil is imported. About 70% of India’s electricity is generated by coal. Yet there are sizeable strides are being made in renewable energy. India has a rapidly growing wind energy base, and it has the largest solar cooking program in the world.

While non-renewable sources dominate, some countries get a sizeable percentage of their electricity from renewable resources. For example, about 67% of New Zealand’s electricity demand is met by hydroelectric. Renewable resources, primarily hydroelectric, generate only 10% of the U.S. electricity, as shown in Figure 4.4.
Figure 4.3. Past and projected global energy use, separated by country category. The OECD, or Organization for Economic Co-operation and Development includes 36 member countries generally recognized as high-income, more-industrialized countries (example member countries include Australia, Canada, Germany, Japan, Mexico, UK, and US). Image from US Energy Information Administration, International Energy Outlook 2011.

Figure 4.4. US energy consumption in 2017 by source, with renewable energy highlighted. Image from the US Energy Information Administration.
4.1.2 Why use renewable energy sources?

The majority of renewable energy sources including solar, wind, water, and biomass can be either directly or indirectly attributed to the sun’s power. The fact that the sun will continue burning for another 4-5 billion years makes it inexhaustible as an energy source for human civilization. With appropriate technology, renewable energy sources can allow for local, decentralized control over their power. Homes, businesses, and isolated communities can use sources such as solar to produce electricity without being near a power plant or being connected to an electrical grid.

In the United States and much of the rest of the world, electricity consumers (homes and businesses) are connected by electrical wires to electricity producers (power plants) through the electrical grid. The grid infrastructure took decades and billions of dollars to establish. Though it would be difficult to generate electricity from coal at home, it is relatively easy to generate electricity from sunlight at small scale, through the use of photovoltaic cells, (see Section 4.2.1) or from wind energy, through the use of wind turbines (see Section 4.3.1). This provides important opportunities to deliver renewable energy resources to locations that may lack the financial capital to establish an electrical grid.

Enhanced use of renewable energy sources can also eliminate problems such as oil spills or pipeline leaks. Most renewable energy sources do not pollute the air with greenhouse gas emissions and other air pollutants associated with fossil fuels. This is especially important in combating climate change and improving human health.

4.2 Solar Energy

Solar energy is the ultimate energy source driving life on earth and many human activities. Though only one billionth of the energy that leaves the sun actually reaches the earth's surface (Figure 4.5), this is more than enough to meet the world’s energy requirements. In fact, almost all other sources of energy, renewable and non-renewable, are actually stored forms of solar energy. Solar energy itself is a renewable energy source when energy from the sun is converted to heat or electricity. The difficulties lie in harnessing the energy. Solar energy has been used for centuries to heat homes and water. Modern technology (e.g., photovoltaic cells) has provided a way to produce electricity from sunlight. In 2017, 6% of the renewable energy (<1% of the total energy) consumed in the United Stated was from solar energy, mostly through the use of photovoltaic cell technology.

Though solar energy has great potential, there are also some downsides. Solar energy is not evenly distributed across the globe, making some locations better suited to solar energy investment than others. Also, even in locations with great solar potential, the solar energy can only be gathered while the sun is shining. This means that little to no energy can be generated at night or on cloudy days. Since sunlight can’t be stored and used on demand (like coal, oil, or
even biomass can), the challenge of intermittent power can be difficult to overcome. Still, many have found solar energy to be an excellent supplemental source of power, as demonstrated by the increasing popularity of installing solar panels on home, business, and municipal rooftops.

![Figure 4.5](image1.png)

**Figure 4.5.** From left to right, an image of the Mars Observer in Mars Orbit showing the solar panel. (Credit: NASA/JPL); and an image of the Sun photographed at 304 angstroms by the Atmospheric Imaging Assembly (AIA 304) of NASA’s Solar Dynamics Observatory (SDO). This is a false-color image of the Sun observed in the extreme ultraviolet region of the spectrum. (Credit: NASA/SDO).

### 4.2.1 Passive and active solar power

**Passive solar power** manipulates the sun’s energy to provide heating or cooling, without the use of special devices or modern technology. These heating and cooling strategies have been used historically, such as natural ventilation, solar heat gain, solar shading and efficient insulation (example in Figure 4.6). Passive solar space heating happens when the sun shines through the windows of a building and warms the interior. Building designs that optimize passive solar heating usually have south-facing windows that allow the sun to shine on solar heat-absorbing walls or floors during the winter. The solar energy heats the building by natural radiation and convection and the heat is trapped, absorbed and stored by materials with high thermal mass (usually bricks or concrete) inside the house. The heat is released at night when needed to warm up the building as it loses heat to the cooler outdoors. Window overhangs or shades block the sun from entering the windows during the summer to keep the building cool.
Active solar power systems harness the sun’s energy through the use of specialized devices that transform this energy into another form. Some of the more common examples of active solar devices are described below.

Photovoltaic (PV) cells

Solar photovoltaic (PV) devices, or solar cells, change sunlight directly into electricity. These make up the solar panels that you are probably most used to seeing (Figure 4.7). Photovoltaics use semiconducting materials such as silicon to produce electricity from sunlight. When light hits the cells, the material produces free electrons that migrate across the cell, creating an electric current. Small PV cells can power calculators, watches, and other small electronic devices. Arrangements of many solar cells in PV panels and arrangements of multiple PV panels in PV arrays can produce electricity for an entire house or business (Figure 4.7). Some PV power plants have large arrays that cover many acres to produce electricity for thousands of homes. These are often termed “solar farms.”

Hundreds of thousands of houses and buildings around the world have PV systems on their roofs. Many multi-megawatt PV power plants have also been built. Covering 4% of the world’s desert areas with photovoltaics could supply the equivalent of all of the world’s electricity. The Gobi Desert alone, if it were completely covered in PV panels, could supply almost all of the world’s total electricity demand. See a comparison of power plants in Table 4.1.
Solar thermal collectors

An alternate type of active solar power device, solar thermal collectors may require the input of some energy to pump a heat-absorbing fluid medium through a collector to store and distribute the energy. Fans or pumps circulate air or heat-absorbing liquids through collectors and then transfer the heated fluid directly to a room or to a heat storage system. The collectors absorb and transfer heat to a fluid (water or air) which is then circulated to provide heating to a
building. The solar collectors are either concentrating or non-concentrating. In the non-concentrating collectors, the surface area that intercepts the solar radiation is the same as the area absorbing the radiation. Flat-plate collectors are the most common type of non-concentrating collectors and are used to heat air or water to temperatures of less than 100°C. This type of solar thermal collector is shown in Figure 4.8. In concentrating collectors, the surface area intercepting the solar radiation is greater, sometimes hundreds of times greater, than the absorber area. The collector focuses or concentrates solar energy onto an absorber. The collector usually moves so that it maintains a high degree of concentration on the absorber.

Solar thermal systems

Solar thermal systems, like the one in Figure 4.9b use concentrating solar collector systems to collect and concentrate sunlight to produce the high temperature heat needed to generate electricity. All solar thermal systems have solar energy collectors with two main components: reflectors (mirrors) that capture and focus sunlight onto a receiver. In most types of systems, a heat-transfer fluid is heated and circulated in the receiver and used to produce steam. The steam is converted into mechanical energy in a turbine, which powers a generator to produce electricity. Solar thermal power systems have tracking systems that keep sunlight focused onto the receiver throughout the day as the sun changes position in the sky.

Figure 4.9: (left photo) Rooftop Solar Installations on Douglas Hall at the University of Illinois at Chicago has no effect on land resources, while producing electricity with zero emissions. Source: Office of Sustainability. (right photo) Solucar PS10 solar power tower in Andalusia, Spain, is a solar thermal system that generates electricity commercially. (Photo by Afloresm Solucar PS10 CC BY 2.0)
4.2.2 Environmental impacts of solar energy

Solar energy has minimal impact on the environment, depending on where it is placed. The manufacturing of photovoltaic (PV) cells generates some hazardous waste from the chemicals and solvents used in processing, including sodium hydroxide and hydrofluoric acid. Typically, conventional fuel sources, such as fossil fuels, are used to provide energy for PV manufacturing, resulting in the release of greenhouse gases during manufacturing. Ideally, these would be offset by the future use of the solar panel.

Often, solar arrays are placed on roofs of buildings or over parking lots or integrated into construction in other ways. However, large systems and solar farms may be placed on large areas of land. These often occur in deserts, where the fragile ecosystems could be damaged by the presence of large solar panels. Some solar thermal systems use potentially hazardous fluids (to transfer heat) that require proper handling and disposal. Concentrated solar systems may need to be cleaned regularly with water, which is also needed for cooling the turbine-generator. Using water from underground wells may affect the ecosystem in some arid locations.

4.3 Wind Power

Wind power is a renewable energy source that uses the energy of moving air to generate electricity. Winds are caused by differences in atmospheric pressure across the globe. These pressure differentials themselves are largely caused by the temperature differences that result from uneven solar heating across the Earth. In this way, wind power is an indirect form of solar energy. Similar to solar energy, some locations of the Earth’s surface possess greater wind speeds, and therefore a greater capacity for the harvesting of wind energy. Many locations with excellent wind power capacity are found on top of the ocean, and are beginning to be utilized through the construction of offshore wind farms.

The most common way to collect and transform the wind’s energy into a usable form is through wind turbines (Figure 4.10a). These turbines use blades to collect the wind’s kinetic energy. This technology has been in use for hundreds of years in the form of windmills. While traditional windmills used wind energy to pump water or grind grain, modern wind turbines convert this energy to electricity through the use of a generator. Wind flows over the blades of a turbine creating lift (similar to the effect on airplane wings), which causes the blades to turn. The blades are connected to a drive shaft that turns an electric generator, which produces electricity (Figure 4.10b).
Figure 4.10. (left photo) This wind turbine in the Thames Estuary in the UK is an example of induction at work, (credit: Phault, Flickr). (right image) Wind pushes the blades of the turbine, spinning a shaft attached to magnets. The magnets spin around a conductive coil, inducing an electric current in the coil, and eventually feeding the electrical grid.

Wind turbines are becoming a more prominent sight across the United States, even in regions that have less wind potential. Wind turbines do not release emissions that pollute the air or water, and they do not require water for cooling. As of early 2017, the total US wind power installed capacity was 82,183 megawatts (MW). This is up from the 40,181 MW of wind power capacity installed at the end of 2010.

Since a wind turbine (Figure 4.8) has a small physical footprint relative to the amount of electricity it produces, many wind farms are located on crop, pasture, forest land, or coastal areas. They contribute to economic sustainability by providing extra income to farmers and ranchers, allowing them to stay in business and keep their property from being developed for other uses. For example, energy could be produced by installing wind turbines in the Appalachian Mountains of the United States instead of engaging in mountain top removal for coal mining.

Similar to PV solar systems, wind turbines are practical at the small scale, and can be used in remote areas to generate electricity even in the absence of electrical grid infrastructure. Also similar to PV solar systems, it is impossible to store wind and use it on demand. Because of this, wind turbine may be intermittent in their production of power – only producing electricity when the wind is blowing. For this reason, many individuals choose to use them as a supplemental, rather than primary, electricity source.

4.3.1 Environmental impacts of wind power

Offshore wind turbines on lakes or the ocean may have smaller environmental impacts than turbines on land. Still, wind turbines do have a few environmental challenges. There are aesthetic concerns to some people when they see them on the landscape. A few wind turbines have caught on fire, and some have leaked lubricating fluids, though this is relatively rare.
Wind turbines do produce noise pollution, which can impact both human and animal populations. Locating wind turbines offshore helps to reduce noise pollution in most instances. Additionally, turbines have been found to cause bird and bat deaths particularly if they are located along their migratory path. This is of particular concern if these are threatened or endangered species. There are ways to mitigate that impact and it is currently being researched.

There are some small impacts from the construction of wind projects or farms, such as the construction of service roads, the production of the turbines themselves, and the concrete for the foundations. However, overall life cycle analysis has found that turbines make much more energy than the amount used to make and install them.

4.4 Hydroelectric Power

Hydroelectric power, also known as hydropower, is the second largest source of renewable energy used, next to biomass energy. Similar to wind power, hydropower has been used for hundreds of years as the kinetic energy from moving water was used to turn a mill and grind grain. See an image of a traditional water mill in Figure 4.11. For most types of hydropower, locations are limited to regions with rivers that are large enough and have a flow strong enough to support a hydropower station. At times when the river is low, there may now be sufficient flow to operate hydropower stations, causing this form of energy to be somewhat limited by both geographical and seasonal factors.

Figure 4.11. Traditional water mill dating from the twelfth century in Braine-le-Château, Belgium. Note that the mill itself is not in operation at the time this picture was taken. When operating, water will move the slats of the mill, causing the rotor to turn, and providing power for machinery inside the building. Credit: Pierre79, free of use, https://fr.wikipedia.org/wiki/Fichier:Braine_le_Chateau,Belgium,moulin_banal.JPG.
4.4.1 Storage hydropower

The majority of hydropower in the world is in the form of *storage hydropower*, in which *dams* built across a river to block the flow of river water. The water stored behind the dam contains potential energy and when released, the potential energy is converted to kinetic energy as the water rushes down (see Chapter 3 for a review of forms of energy). In addition to providing a source of hydroelectric power, the dam also creates a *reservoir*, or manmade lake, in the area upstream of the dam. Many of the lakes in the Southeastern United States are actually manmade reservoirs created by hydropower dams, including Lake Lanier, Lake Hartwell, Lake Oconee, and Lake Sinclair. This has its own environmental consequences, which will be examined in Section 4.4.4.

In modern storage hydropower facilities, this energy is used to turn blades of turbines and causing a generator to generate electricity. Electricity generated in the powerhouse of a dam is transmitted to the electric grid by transmission lines while the water flows into the riverbed below the dam and continues down river. See an image of a storage hydropower facility in Figure 4.12a, and a schematic of the inside of a dam in Figure 4.12c.
Figure 4.12. a) Hydroelectric facility on the Krasnoyarsk Dam in Russia (credit: Denis Belevich); b) turbines inside the Hoover Dam inside Nevada, US (credit: Allison VandeVoort); c) schematic of the inside of a storage hydropower facility (credit: Tennessee Valley Authority / Tomia).

Many of the largest power plants in the world are storage hydropower facilities, including the Three Gorges Dam in China, the world’s largest power plant by installed capacity at 22,500 MW, and the Grand Coulee Dam in Washington, US at over 6,800 MW. Figure 4.12b shows the Hoover Dam Power Plant located on the Colorado River. In the U.S., hydroelectric plants account for about 10% of total production and account about 35% of the United States'
renewable energy consumption. Despite very large installed capacities, most storage hydropower facilities operate at capacities well below their maximum potential. This is often due to limitations such as water flow rate and capacity of the ecosystem below the dam to accept large amounts of water at once. Energy produced can be calculated and modeled as shown in Figure 4.13. See a comparison of power plants in Table 4.1.

![Figure 4.13](image1.png)

**Figure 4.13.** (a) Water gushes from the base of the Studen Kladenetz dam in Bulgaria. (credit: Kiril Kapustin; http://www.ImagesFromBulgaria.com) (b) In the absence of significant resistance, water flows from the reservoir with the same speed it would have if it fell the distance $h$ without friction.

### 4.4.2 Pumped-storage hydropower

Another approach to hydropower involves pumping water from a lower reservoir to a higher reservoir and then allowed to flow downhill through a turbine, generating electricity. This approach is called **pumped-storage hydropower**.

![Figure 4.14](image2.png)

**Figure 4.14.** Upper basin of a pumped-storage facility in Rönkhausen, Germany (credit: Dr.G. Schmitz, [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)).
A pumped-storage facility uses energy to pump water from a natural source (ocean, lake, or river) to an upper basin, shown in Figure 4.14. This process builds a store of potential energy in the water in the upper basin. When energy is needed, water from the upper basin is released through a controlled channel back into the natural source. While this is happening, the water flowing down, out of the upper basin, turns turbines in the channel, which power a generator to produce electricity. Though pumped-storage facilities produce no net energy, they are useful for storing energy to use in times of high demand. The upper basin can be filled during a time when energy is relatively inexpensive, and then emptied when energy is costly. Pumped-storage facilities can also be paired with other forms of renewable energy, such as solar or wind, to store energy from these intermittent sources.

4.4.3 Run-of-river hydropower

Run-of-river hydropower is an alternative approach to hydropower that is considered less disruptive than storage hydropower facilities. It involves diverting a portion of the river’s water through a pipe or channel containing turbines, to power a generator and produce electricity. This water is then returned to the river (Figure 4.15). The largest environmental benefit to run-of-river systems is that they do not create a large reservoir of water above the dam, and allow the river to flow at its more natural pace.

Figure 4.15. South Slocan Dam on the Kootenay River in British Columbia, Canada. Note the pipes leading to the dam facility, which contain water diverted from the Kootenay River and power the run-of-river station (credit: Doug McDonell, [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0)).
4.4.4 Environmental impacts of hydropower

Hydropower is a renewable source of energy since it does not directly produce emissions of air pollutants, it consumes no non-renewable fuel sources, and the source of power is constantly regenerated. However, hydropower dams, reservoirs, and the operation of generators can have serious environmental impacts. A dam that is used to create a reservoir or to divert water to a run-of-river hydropower plant can obstruct migration of fish to their upstream spawning areas in areas where salmon must travel upstream to spawn, such as along the Columbia River in Washington and Oregon. Turbines kill and injure some of the fish that pass through the turbine, though prevention of this is attempted in most facilities. This problem has been partially alleviated in some systems by using fish ladders that help the salmon get up the dams.

Storage hydropower systems are typically the most impactful of all forms of hydropower through their creation of a reservoir. This action destroys the terrestrial ecosystem that previously inhabited the reservoir area, and impacts populations of plants and animals on the adjacent land as food sources and migration paths are disrupted. Construction of reservoirs may cause natural areas, farms, and archeological sites to be covered and force populations to relocate and result in the loss of scenic rivers. The construction of the Three Gorges Dam on the Yangtze River in China, pictured in Figure 4.16, caused the relocation of over 1 million residents.

![Figure 4.16](https://commons.wikimedia.org/wiki/File:200407-sandouping-sanxiadaba-4.med.jpg?cb=20201022150141&version=1)

*Figure 4.16. Image of a portion of boat locks and the reservoir upstream of the Three Gorges Dam in Hubei Province, China. This photograph was taken in 2004, while the dam was still under construction. The dam itself was completed in 2006, with the hydropower station and shop locks completed in 2012 (credit: Shizhao, [https://commons.wikimedia.org/wiki/File:200407-sandouping-sanxiadaba-4.med.jpg], CC BY-SA 3.0).*

Even downstream of the dam, environmental impacts are felt. A reservoir and operation of the dam can affect the natural water habitat due to changes in water temperatures, chemistry, flow characteristics, and silt loads, all of which can lead to significant changes in the ecology and physical characteristics of the river upstream and downstream.

Carbon dioxide and methane may also form in reservoirs where water is more stagnant than it would have been in a flowing river, and be emitted to the atmosphere. The exact amount of
greenhouse gases produced from hydropower reservoirs varies significantly by location and even by season. If the reservoirs are located in tropical and temperate regions, including the United States, those emissions may be equal to or greater than the greenhouse effect of the carbon dioxide emissions from an equivalent amount of electricity generated with fossil fuels (EIA, 2011 p. 333).

4.4.5 Potential of tidal power

Tidal power takes advantage of the natural kinetic power of the ocean’s tides to turn turbines and generate electricity. In this form of electricity generation, turbines are placed in zones of the ocean with significant tides and currents, and the power of flowing water is used to turn the blades of a turbine to generate electricity. Typically, these turbines are located along a seawall that extends from the shore into the ocean. Tidal power systems are still very new, though some examples are emerging. The Rance Tidal Power Station was the world’s first tidal power station. The Rance station opened in 1966 in Brittany, France, and operates at 240 MW installed capacity. Sihwa Lake Tidal Power Station (Figure 4.17), currently the largest tidal power station by installed capacity in the world at 254 MW, opened in Gyeonggi Province, South Korea in 2012.

![Sihwa Lake Tidal Power Station](https://en.wikipedia.org/wiki/Sihwa_Lake_Tidal_Power_Station#/media/File:Sihwa_Lake_Tidal_Power_Station_01.png)

**Figure 4.17.** Seawall of Sihwa Lake Tidal Power Station in South Korea (credit: 평크로즈, CC BY 2.0 kr, https://en.wikipedia.org/wiki/Sihwa_Lake_Tidal_Power_Station#/media/File:Sihwa_Lake_Tidal_Power_Station_01.png).

The primary environmental impacts of tidal power come from the establishment of the seawall, including the resources required for construction. Additionally, marine life in the
immediate region are likely impacted by presence and operation of the seawall. Overall, these impacts are much lower than experienced with traditional storage hydropower facilities.

4.5 Geothermal Energy

**Geothermal energy** uses heat from the Earth's internal geologic processes to produce electricity or provide heating. The subsurface temperature of the Earth provides an essentially endless energy resource. The energy harvested in a geothermal power plant is the same energy that forms geysers and hot springs. The heat from the Earth's **core** continuously flows outward. Sometimes the heat, as magma, reaches the surface as lava, but it usually remains below the Earth's **crust**, heating nearby rock and water – sometimes to levels as hot as 370°C (Figure 4.18). When water is heated by the earth’s heat, hot water or steam can be trapped in permeable and porous rocks under a layer of impermeable rock and a geothermal reservoir can form.


A geothermal system requires heat, permeability, and water. To develop electricity from geothermal resources, wells are drilled in a location with high geothermal potential. This is typically a region containing naturally superheated **groundwater**. Groundwater percolates down through cracks in the subsurface rocks until it reaches rocks heated by underlying magma, and the heat converts the water to steam. Many areas with strong seismic activity, including earthquakes and volcanoes, also possess high geothermal potential. Examples include the country of Iceland, and many regions of California and the North American Pacific Coast. According to the World Energy Council, total geothermal installed capacity was 83,400 MW by the end of 2015, with 21,000 MW in the US alone.
Figure 4.19. (left photo) Installing a Geothermal Pipe System Drilling to install geothermal ground source pipe system. Source: Office of Sustainability. (right image) Electricity generation at a moderate-temperature hydrothermal system. The geothermal water is used to boil a second fluid (isobutane in this example) whose vapor then drives a turbine generator. The wastewater is injected back into the subsurface. Source: USGS, https://commons.wikimedia.org/wiki/File:Diagram-BinaryGeothermal.jpg, public domain.

Geothermal wells bring the superheated water or steam to the surface, where its heat energy is converted into electricity by a generator at a geothermal power plant (Figure 4.19b). Wells can also be dug to tap the steam reservoir and bring it to the surface to drive turbines and produce electricity (Figure 4.19a). Geothermal energy can be used for electricity production, for commercial, industrial, and residential direct heating purposes, and for efficient home heating and cooling through geothermal heat pumps.

4.5.1 Environmental impacts of geothermal energy

The environmental impact of geothermal energy depends on how it is being used. Direct use and heating applications have almost no negative impact on the environment. Geothermal power plants do not burn fuel to generate electricity, so their emission levels are very low. Some carbon dioxide (CO₂) and methane (CH₄) gas are emitted, but to a much smaller degree than the combustion of fossil fuels or biomass. Very small quantities of other gases including ammonia and hydrogen sulfide can also be produced. To help mitigate emissions impacts, geothermal plants use scrubber systems to clean the emissions of the hydrogen sulfide that is naturally found in deep steam and hot water. They emit 97% less acid rain-causing sulfur compounds than are emitted by fossil fuel plants.

Even though geothermal energy is renewable, not every plant built to capture this energy will be able to operate indefinitely because the energy relies on groundwater recharge. If the heated water is used faster than the recharge rate of groundwater, the plant will eventually run
out of water. The Geysers, a famous geothermal power plant in California, started experiencing this and operators responded by injecting treated municipal wastewater into the ground to replenish the supply. Also, patterns of geothermal activity in the Earth’s crust naturally shift over time and an area that produces hot groundwater now may not always so do. The water of many hot springs is laced with salts and minerals that can corrode equipment, shorten the lifetime of plants, and increase maintenance costs. See a comparison of power plants in Table 4.1.

Electrical power is restricted to regions where energy can be tapped from naturally heated groundwater but most areas of the world are not rich in naturally heated groundwater. Engineers are trying to overcome this by drilling deeply into dry rock, fracture the rock and pump in cold water which becomes heated and drawn up through an outlet well and used to generate power. However, this approach is said to trigger minor earthquakes.
<table>
<thead>
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<th>Energy source</th>
<th>Largest in US</th>
<th>Capacity (MW)</th>
<th>Largest in world</th>
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<td><strong>Capacity (MW)</strong></td>
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Table 4.1. Comparison of major renewable and non-renewable power plants, worldwide. Most data updated as of 2017.
4.6 Biomass Energy

Biomass energy is from the energy stored in materials of biological origin such as plants and animals. Biomass energy is the oldest energy source used by humans. Until the Industrial Revolution prompted a shift to fossil fuels in the mid-18th century, biomass energy was the world's dominant fuel source. It includes direct combustion of solid biomass to provide energy for heating, cooking, and even generating electricity. Biomass can also be converted into a liquid biofuels used to power vehicles such as ethanol from corn, sugarcane residue and soybeans or even used cooking oil for biodiesel. Biomass energy can also be harvested through gaseous biomass, sometimes called biogas, in the form of methane. Currently, about 10 percent of the world's energy comes from biomass (Figure 4.2). Biomass is most frequently used as a fuel source in many less-industrialized nations, but with the decline of fossil fuel availability and the increase in fossil fuel prices, biomass is increasingly being used as a fuel source even in more-industrialized nations.

Biomass energy may have the potential be considered to be carbon neutral because the plants that are used to make them (such as corn and sugarcane for ethanol, or soy beans and palm oil trees for biodiesel) take up CO$_2$ from the atmosphere through photosynthesis as they grow and may offset the CO$_2$ produced when burned. If the biomass is not burned for energy generation, the carbon contained in the biomass would still be returned to the atmosphere as CO$_2$ when the organisms die and decompose to complete the cycle. Read more about carbon neutrality in Box 4.1.
When biomass is burned directly, without the conversion to a liquid or gaseous form first, this is called direct combustion. The most common source for direct combustion is wood, but energy can also be generated by burning animal manure (dung), herbaceous plant material (non-wood), peat (partially decomposed plant and animal tissues), or converted biomass such as charcoal (wood that has been partially burned to produce a coal-like substance). In many of the examples above, these fuels are burned on demand at the small scale, such as lighting a fire.
to cook dinner or heat a household. This is common in many less-industrialized nations, where some households may not have access to municipal heat or electricity for these purposes.

![Kinleith Mill, a paper and pulp mill in Waikato, New Zealand. The building at the right is a cogeneration (produces both heat and electricity) power plant burning wood waste. The energy is then used to power paper production. (credit: Ingolfson, https://commons.wikimedia.org/wiki/File:Kinleith_Mill_And_Cogen_Plant.jpg, public domain).](https://commons.wikimedia.org/wiki/File:Kinleith_Mill_And_Cogen_Plant.jpg)

**Figure 4.20.** Kinleith Mill, a paper and pulp mill in Waikato, New Zealand. The building at the right is a cogeneration (produces both heat and electricity) power plant burning wood waste. The energy is then used to power paper production. (credit: Ingolfson, https://commons.wikimedia.org/wiki/File:Kinleith_Mill_And_Cogen_Plant.jpg, public domain).

Using wood and charcoal made from wood, for heating and cooking can replace fossil fuels and may result in lower CO₂ emissions. However, wood smoke contains harmful pollutants like carbon monoxide and particulate matter (see Chapter 5). The safest way to use direct combustion for home heating is through a modern or updated wood stove designed to reduce the amount of particulate matter in its emissions. There are also environmental impacts of small-scale direct combustion. When wood is harvested from downed trees or thinned wood lots, environmental impact is minimal. However, in places where wood and charcoal are major cooking and heating fuels, as in some densely populated regions of less-industrialized countries, the wood may be harvested faster than trees can grow, resulting in deforestation.

Biomass can also be used on a larger scale, where small power plants are powered by biomass such as woodchips (Figure 4.20). For instance, Central State Hospital, Milledgeville, GA had a woodchip burning plant that was the most advanced system available for its time. Colgate University in Hamilton, New York, has had a wood-burning boiler since the mid-1980's that processes about 20,000 tons of locally and sustainably harvested wood chips, the equivalent of 1.17 million gallons (4.43 million liters) of fuel oil, avoiding 13,757 tons of emissions, and saving the university over $1.8 million in heating costs. The University's steam-generating wood-burning facility now satisfies more than 75 percent of the campus's heat and domestic hot water needs.

Waste products of various industries and processes such as lumber mill sawdust, paper mill sludge, yard waste, oat hulls from an oatmeal processing plant, woody debris from logging,
organic waste from feedlots, and residue from crops can also be used for energy. Waste to energy processes are gaining renewed interest as they can solve two problems at once: 1) disposal of waste as landfill capacity decreases; and 2) production of energy from a renewable resource.

In the United States, several plants have been constructed to burn urban biomass waste, such as municipal solid waste (MSW), or garbage, and use the energy to generate electricity. Since the fuel source is less standardized than coal and hazardous materials may be present, MSW, incinerators and waste-to-energy power plants are very stringently regulated by the US Environmental Protection Agency (EPA). These power plants are required to use scrubbers and other anti-pollution devices to rid stack gases of harmful materials.

Many of the environmental impacts are similar to those of a coal plant like air pollution, ash generation, etc. (see Chapter 3). The ash from these plants may contain high concentrations of various metals that were present in the original waste. If the ash is clean enough, it can be recycled as a MSW landfill cover or to build roads, cement block and artificial reefs. Also, while incinerating at high temperature many of the toxic chemicals may break down into less harmful compounds.

### 4.6.2 Gaseous Biomass

Organic material can be converted to methane, the main component of natural gas, through the process of bacterial anaerobic decomposition, also known as fermentation. The methane produced is essentiallychemically identical to the methane harvested as the fossil fuel natural gas. A wide variety of organic materials can be used as the feedstocks for gaseous biomass production, including municipal sewage, MSW, livestock manure, kitchen, and garden scraps. See an image of a gaseous biomass power plant in Figure 4.21. Burning methane produced from manure provides more heat than burning the dung itself, and the sludge left over from bacterial digestion is a rich fertilizer, containing healthy bacteria as well as most of the nutrients originally in the dung.

This fermentation process actively happens within municipal landfills on its own. In fact, municipal landfills are active sites of methane production contributing annually to methane in the atmosphere and to global warming. While all landfills must monitor methane gas release, some are capturing the gas and burning it to generate electricity at power plants or supply it to homes for heating. This is common both in the US and worldwide. The electricity may replace electricity produced by burning fossil fuels and result in a net reduction in CO$_2$ emissions. See a comparison of power plants in Table 4.1.

Methane does release carbon dioxide when burned, along with a few other gases (see Chapter 3), though these emissions are lower than that of coal. Burning methane releases CO$_2$ and although CO$_2$ is a greenhouse gas, its global warming potential is much lower than that of
methane (see Chapter 6). Additional significant environmental impacts come from the construction of the plant itself. Also, since this methane if from organic waste resulting from ongoing photosynthetic processes, it is has the potential to be carbon-neutral, unlike CO₂ from fossil fuels (see Box 4.1 for a full discussion of carbon neutrality).

**Figure 4.21.** Biomass gasification plant at the Dockside Green community in Victoria, British Columbia, Canada. This operation converts wood waste into methane gas that can be used for heating and hot water (credit: John Newcomb, [https://commons.wikimedia.org/wiki/File:Biomass_energy_generator_of_Dockside_Green..READ_INFO_IN_PANORAMIO-COMMENTS_-_panoramio.jpg, CC BY-SA 3.0](https://commons.wikimedia.org/wiki/File:Biomass_energy_generator_of_Dockside_Green..READ_INFO_IN_PANORAMIO-COMMENTS_-_panoramio.jpg, CC BY-SA 3.0)).

### 4.6.3 Liquid Biofuels

Biofuels are transportation fuels produced from plant sources and used to power vehicles. The most common ones are ethanol and biodiesel. **Ethanol**, also known as ethyl alcohol or grain alcohol, is produced by fermenting crops such as corn or sugarcane. In most instances, this ethanol is then mixed with conventional petroleum gasoline to make a blend. Common gas blends in the United States include **E10** (10% ethanol, 90% petroleum gasoline) and **E85** (85% ethanol, 15% petroleum gasoline). Most regular gas at a gas station, unless it is marked “ethanol free,” contains up to 10% ethanol, making it E10. A standard gasoline car engine is able to use E10 well, though fuel economy may decrease by about 3%. Special engines are required to use higher-ethanol blends, such as E85. These are often marketed as **flex-fuel vehicles**.

As an additive, ethanol lowers reliance on conventional oil and reduces carbon dioxide emissions. In Brazil, which has a sizeable ethanol industry based on sugarcane, all gasoline sold contains 25% alcohol, and over 70 percent of the cars sold each year are flex-fuel vehicles. Ethanol-gasoline mixtures burn cleaner than pure gasoline but are more volatile and thus have
higher "evaporative emissions" from fuel tanks and dispensing equipment. These emissions contribute to the formation of harmful, ground level ozone and smog. Gasoline requires extra processing to reduce evaporative emissions before it is blended with ethanol.

Biodiesel, which is essentially vegetable oil, can also be derived from a wide range of plant sources, including rapeseed, sunflowers, and soybeans, and even spent fryer oil from local restaurants! Biodiesel is often blended with petroleum diesel. Conventional diesel engines can typically use blends up to 5% biodiesel, known as B5. Some adapted diesel vehicles, and older conventional diesel engines, can use pure biodiesel, or B100. Biodiesel burns more cleanly than its petroleum-based counterpart, and the use of biodiesel can reduce pollution from heavy-duty vehicles such as trucks and buses. Compared to petroleum diesel, biodiesel combustion produces less sulfur oxides, particulate matter, carbon monoxide, and unburned and other hydrocarbons, but more nitrogen oxide.

Calculating the net energy or CO$_2$ generated or reduced in the process of producing the biofuel is crucial to determining its environmental impact. The vast majority of ethanol made in the US, for example, is made from corn kernels. These have a very high sugar content, and ferment easily into ethanol. However, this is also the edible portion of the corn plant. In 2016, about 36% of the US corn crop was used for fuel ethanol production. Ethical questions have been raised as to whether it is appropriate to use a food crop to produce fuel instead. Also, in some parts of the world, large areas of natural vegetation and forests have been cut down to grow sugarcane for ethanol and soybeans and palm-oil trees to make biodiesel. This is not sustainable land use.

Biofuels may be derived from parts of plants not used for food, such as the corn stalks. This is called cellulosic ethanol, and is generally seen to have a lower environmental impact than traditional corn-based ethanol. Cellulosic ethanol feedstock includes native prairie grasses, fast growing trees, sawdust, and even waste paper. It is more difficult to ferment high-cellulose portions of the plant into ethanol, but this is an active area of research right now.

### 4.6.4 Environmental Impacts of Biomass Energy

A major challenge of biomass is determining if it is really a more sustainable option. A lifecycle analysis approach must often be used to assess impact. This approach considers all resources required to make, transport, use, and dispose of the product. A lifecycle analysis approach could be used to analyze both biomass energy and fossil fuel energy.

The energy content of some biomass energy sources may not be as high as fossil fuels, so more must be burned to generate the same energy. It often takes energy to make energy and biomass is one example where the processing to make it may not be offset by the energy it produces. If conventional agriculture crops like corn or soybeans are used, they require major quantities of fossil fuel to manufacture fertilizer, run farm machines, and ship the fuel to
markets, so these biofuels do not always offer significant net energy savings over gasoline and diesel fuel. In such instances, biofuels may not be carbon-neutral because the process of producing the biofuels results in more CO\(_2\) added to the atmosphere than that removed by the growing crops. Even if the environmental impact is net positive, for example, if renewable energy sources are used to make the biofuels, the economic and social effects of growing plants for fuels need to be considered. The land, fertilizers, water, and energy used to grow biofuel crops could be used to grow food crops instead. The competition of land for fuel vs. food can increase the price of food, which has a negative effect on society. It could also decrease the food supply and increase malnutrition and starvation globally.

Trees that are cut for firewood are frequently not replanted. In order to be used sustainably, one tree must be planted for every one cut down. If too much biomass is taken it can reduce forest and grassland contributions to ecosystem services. Forests and grasslands help take CO\(_2\) out of the atmosphere through photosynthesis and the loss of photosynthetic activity results in increased amounts of CO\(_2\) in the atmosphere and contribute to global warming since CO\(_2\) is a greenhouse gas. Burning biomass directly (wood, manure, etc.) produces high particulate material pollution (see chapter 6 on Air Pollution), produces CO\(_2\) and deprives the soil of nutrients it normally would have received from the decomposition of the organic matter. Each type of biomass energy source, therefore, must be evaluated for its full life-cycle impact in order to determine if it is really advancing sustainability and reducing environmental impacts.

4.7 Other Renewable Energy Sources

4.7.1 Hydrogen fuel

Hydrogen fuel may be an important clean fuel of the future. Hydrogen gas does not tend to exist freely in the atmosphere, but rather hydrogen atoms bind to other atoms and molecules becoming incorporated in everything from water to organic compounds (see Chapter 1 for a chemistry review). Therefore, to obtain hydrogen gas for fuel, energy is needed to force these substances to release their hydrogen atoms. One such procedure is known as electrolysis in which an electric current is passed through water to break down the water molecule into oxygen and hydrogen (Figure 4.22). Hydrogen can also be produced from hydrocarbons such as natural gas and coal, fermentation of plant waste material, and using algae.

Some energy experts believe that combining hydrogen fuel and electricity could serve as a basis for a clean, safe, and energy efficient energy system. Electricity generated from intermittent renewable sources such as wind and solar can be used to produce hydrogen fuel for fuel cells that would then generate electricity to power vehicles, computers, heat homes and many other uses. An energy system based on hydrogen could alleviate dependence on
foreign fuels and help fight climate change. Hydrogen is the most abundant element in the universe and we will never run out of it.

**Figure 4.22 a)** Schematic of the electrolysis process through which hydrogen fuel is formed. Water (H₂O) in the form of steam enters the electrolyser. Electrical charges from the cathode (+) and anode (-) force the separation of water into hydrogen gas (H₂) and oxygen (O₂). This process requires high temperatures and energy input. Image remix, credit Grimlock, [CC BY-SA 3.0](https://commons.wikimedia.org/wiki/File:High-temperature_electrolysisfr.png). **b)** A set of high-pressure PEM electrolyser stacks used in the production of hydrogen gas (credit: Bexi81, [https://en.wikipedia.org/wiki/High-pressure_electrolysis#/media/File:High-pressure_PEM_electrolyser_stacks.jpg, CC BY-SA 3.0](https://en.wikipedia.org/wiki/High-pressure_electrolysis#/media/File:High-pressure_PEM_electrolyser_stacks.jpg)).

**Hydrogen fuel cell vehicles**

**Fuel cells** are highly efficient miniature power plants that produce electricity using hydrogen fuel in a chemical reaction that is a reverse of the electrolysis process that produced the hydrogen fuel (Figure 4.23). Energy is released by an exothermic electrochemical reaction that combines hydrogen and oxygen ions through an electrolyte material to generate electricity and heat. Major manufacturers, including Toyota, Hyundai, and Honda, are currently selling hydrogen fuel cell vehicles, though this is limited to markets near hydrogen fueling stations. As of January 2018, there are 39 publicly available hydrogen fueling stations in the US. The majority of these stations are in California, but stations also exist in South Carolina, Massachusetts and Connecticut.
Figure 4.23: The electrochemical processes showing how hydrogen fuel is combined with oxygen generating heat energy along with water as a waste product. Some vehicles that use the fuel cell include buses (photo is a hydrogen fuel bus on Tower Bridge London, photo by Sludge G.), cars (The Toyota Fine N car based on fuel cell technology, photo by Chris 73, CC BY-SA 3.0) and motorcycles (Suzuki Burgman Fuel Cell cutaway model shown here, Photo by Mario CC BY-SA 3.0).

Challenges of hydrogen

Currently, the infrastructure for using hydrogen fuel is lacking and converting a nation such as the United States to hydrogen would require massive and costly development of facilities to produce, store, transport, and provide the fuel. The environmental impact of hydrogen production itself depends on the source of material used to supply the hydrogen. For example, biomass and fossil fuel sources result in carbon-based emissions. Currently, most hydrogen fuel is made using natural gas as the energy source. Some research suggests that leakage of hydrogen from its production, transport, and use could potentially deplete stratospheric ozone. Research into this is still ongoing.

4.7.2 Electric and hybrid vehicles

Electric vehicles use electricity to charge an onboard battery, which operates as the primary fueling source for the vehicle. While there are no carbon dioxide emissions that leave the tailpipe of an electric vehicle, they do require charging (Figure 4.23). Most electric vehicles are charged using the municipal electrical grid, which is gets a significant percentage of its power from the combustion of fossil fuels in most regions of the US (Figure 4.4). Still, the charging and operation of an electric vehicle produces fewer carbon dioxide emissions that the operation of a gasoline vehicle in most instances. The greater the proportion of non-polluting energy sources used to generate electricity, the greater the benefit becomes.

Many electric vehicles are currently on the market in the United States, including models by nearly all of the major automobile manufacturers. One benefit to electric vehicles over
hydrogen fuel cell vehicles is that electric charging stations are much more prevalent than hydrogen fueling stations. Also, electric charging stations can be easily installed at individual residences. Although it might seem very futuristic that the electric car is becoming more and more popular, electric cars have been around for last hundred years, essentially since the invention of the automobile.

The primary limitation of electric cars is the distance that can be travelled between chargings. This is improving with newer models, but typically ranges from about 50-300 miles, depending on the make, model, and age of the vehicle. The charging process often takes several hours. Due to this limitation, many consumers chose hybrid vehicles instead, which combine an electric car battery with a gasoline engine. Hybrid vehicles use a standard gasoline engine as the charging source for their onboard battery. This eliminates the need for plug-in charging in most hybrid models. Nearly every major automobile manufacturer makes one or more hybrid vehicle models, and they are available nationwide.

Figure 4.23. a) This REVAi, an electric car, gets recharged on a street in London. (credit: Frank Hebbert, https://www.flickr.com/photos/f-r-a-n-k/359123912, CC BY 2.0). b) 1985 Mercedes-Benz/Alpha Real "Tour de Sol" Solarmobile; built for the 1985 Tour de Sol Centennial Rally, solar car race from Lake Constance to Lake Geneva, credit: Morio, https://commons.wikimedia.org/wiki/File:Mercedes-Benz_Alpha-Real_Tour_de_Sol_tp_Mercedes-Benz_Museum.jpg, CC BY-SA 3.0

4.8 Policy and Conservation

As we finish this chapter on energy and work, it is relevant to draw some distinctions between two sometimes misunderstood terms in the area of energy use. The first law of thermodynamics, known as the law of conservation of energy, states that the total energy of an isolated system will always remain constant, as energy can be transformed from one form to another, but can never be created nor destroyed.

It is important to distinguish this scientific law from the sustainability-related concept of energy conservation. The philosophy of energy conservation seeks to decrease the amount of energy used by an individual or a group through a variety of methods:
1. Reducing consumption (e.g., turning down thermostats, driving fewer kilometers)
2. Increasing efficiency (e.g., cars with increased gas mileage, installation of energy-saving LED, Energy Star-rated appliances, etc.)

Since energy in an isolated system can never be destroyed nor created, one might wonder why we need to be concerned about our energy resources, since energy is a conserved quantity. The problem is that, even with the latest technological advances, many of our energy transfers are still very inefficient, resulting in much of the energy being transformed into heat rather than doing the work we want it to do. Think about placing your hand on the hood of a car that’s been running, or touching an incandescent light bulb. If you are reading this on a laptop computer, feel the area near the battery. All of us know that heat is generated in these locations, sometimes a great deal of it! This is all wasted energy that was not captured to move the car, produce light, or run the computer. To state it in another way, the potential for energy to produce useful work has been “degraded” in the energy transformation.

A rational energy policy should encourage research by both private industry (e.g., companies and industries) and public institutions (e.g., government research laboratories and universities) to increase our energy efficiency as a nation, and make us economically competitive on the global market, while also ensuring fair access to alternative energy sources and protecting our national resources. The area of alternative energies is constantly changing as new technologies develop everyday. It is essential to consider the costs and benefits of all energy sources: fossil fuels, nuclear power, and alternative energies.

Test your understanding

1. Describe the social, economic, and environmental pros and cons of each of the energy sources we’ve covered in this chapter, as well as the energy sources covered in Chapter 3. Some things to consider: CO₂ emissions, reliance on electrical grid, ability to be used on-demand, ability to be used large- or small-scale, existing infrastructure, etc.
2. Rate the following electricity sources for their contribution to climate change from most to least: biomass, coal, solar, wind, nuclear, natural gas, oil, geothermal, hydroelectric, MSW.
3. Define the term “carbon neutral,” and describe how biomass-based sources have the potential to be carbon neutral. Which biomass-based sources are most likely to actually be carbon neutral?
4. Consider the energy sources primarily used for transportation, as opposed to electricity generation. What are some of the challenges and benefits to each of these sources?
5. Describe the environmental and social concerns associated with biofuels, especially the corn-based ethanol prevalent in the United States.
6. How could the use of alternative energy sources help to increase access to energy and electricity in less-industrialized nations?

**Terms**

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<th>Solar thermal collectors</th>
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