

Chapter 17

Capturing Energy

THE MAIN IDEA



Dirty energy is most convenient, and clean energy is most abundant.

[17.1 Energy through Electricity](#)

[17.2 Fossil Fuels](#)

17.3 The Nuclear Industry

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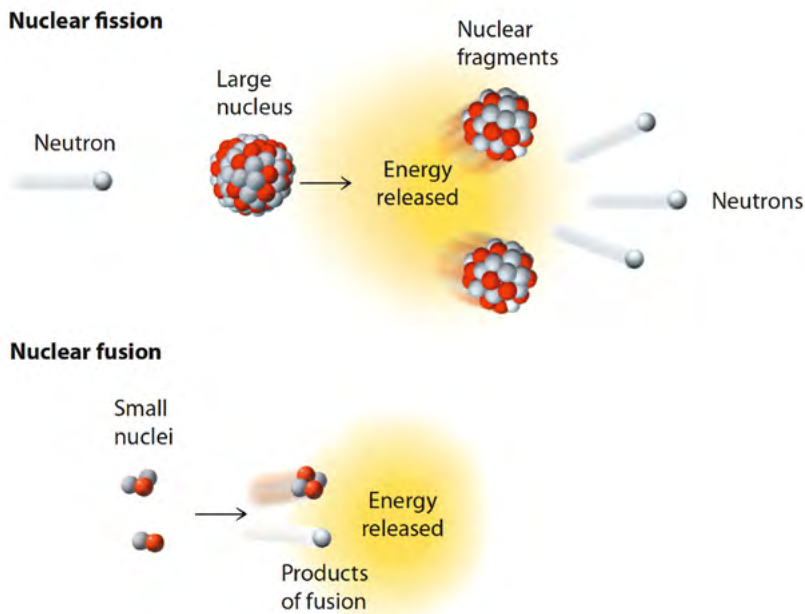
[17.7 Direct Solar Energy](#)

[17.8 Hydrogen Fuel](#)



17.3 The Nuclear Industry

Figure 17.13 summarizes the two forms of nuclear energy discussed in Chapter 5. One form is nuclear fission, which involves the splitting apart of large atomic nuclei, such as uranium and plutonium. The other is nuclear fusion, which involves the combining of two small atomic nuclei, such as deuterium and tritium, into a single atomic nucleus, helium. All commercially operating nuclear power plants to date use nuclear fission. Importantly, these plants produce electrical energy without emitting atmospheric pollutants.

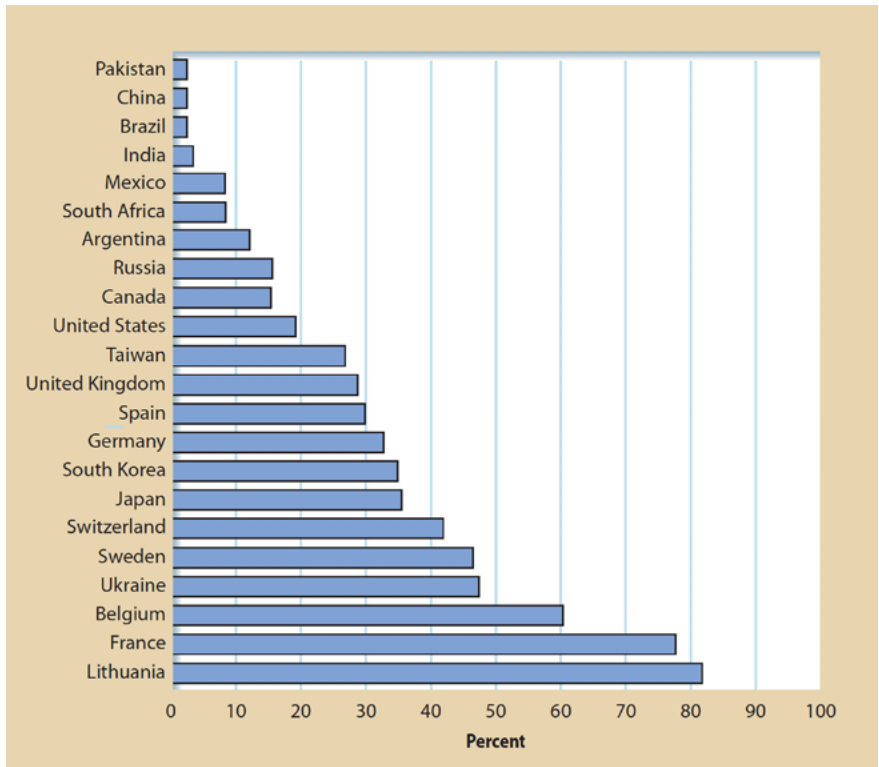


< Figure 17.13

Nuclear fission involves the splitting apart of large atomic nuclei. Nuclear fusion involves the coming together of small nuclei.

Figure 17.14 >

Percentage of electricity generated from nuclear fission reactors in selected countries.

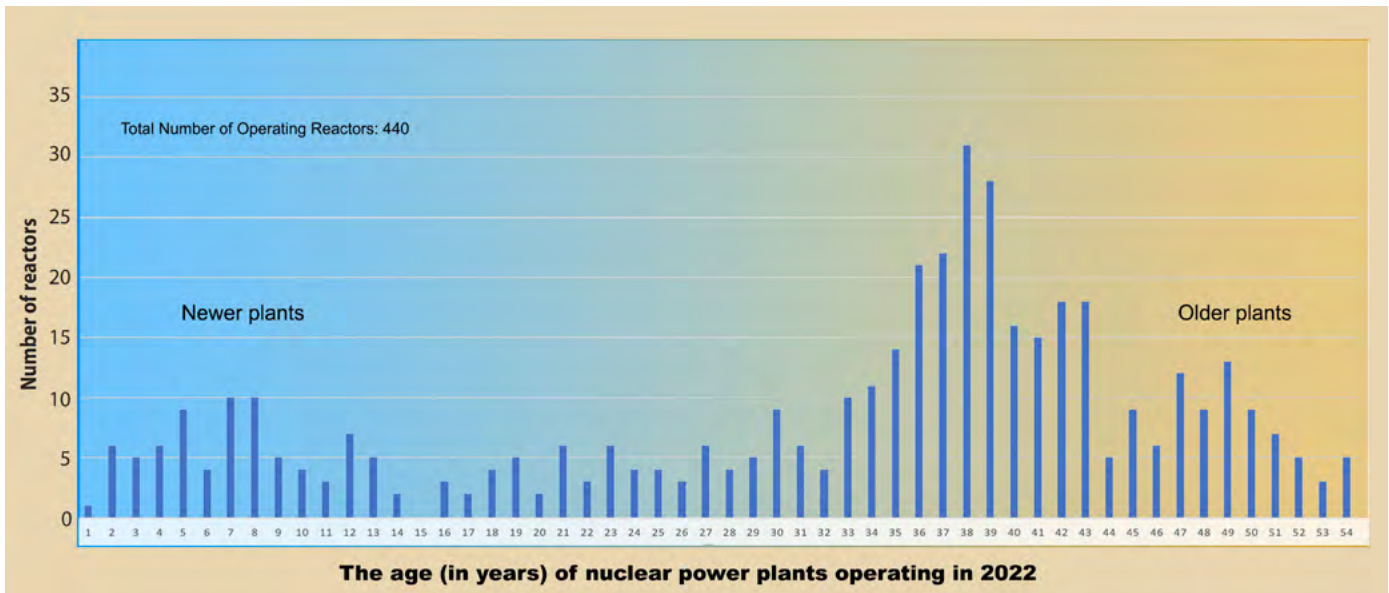


Nuclear fission energy for the commercial production of electricity has been with us since the 1950s. In the United States, about 20 percent of all electrical energy now originates from about 100 nuclear fission reactors situated throughout the country. Other countries also depend on nuclear fission energy, as is shown in **Figure 17.14**. Worldwide, there are about 440 nuclear reactors in operation. The construction of new facilities has slowed markedly over the past three decades due to negative public sentiments. As shown in **Figure 17.15**, most nuclear power plants are over 30 years old.

V Figure 17.15

Most operating nuclear power plants are over 30 years old. (Source: IAEA 2022)

Countries turning to nuclear fission energy have decreased their dependence on fossil fuels and have diminished their output of carbon dioxide, sulfur oxides, nitrogen oxides, heavy metals, airborne particulates, and other atmospheric pollutants. Money that would have been spent on foreign oil payments has been saved.



Without an enormous and concerted conservation effort, the world energy demand is going to increase, especially in light of growing populations and the dire need for economic growth in developing countries. Should nuclear energy production come to a standstill, allowing fossil fuels to accommodate this increased energy demand? Or should we continue to operate existing nuclear power plants—and even build new ones—until the alternative sources of energy discussed later in this chapter become feasible on a large scale? Nuclear advocates suggest a fivefold increase in the number of nuclear power plants over the next 50 years. They argue that nuclear fission is an environmentally friendly alternative to increased dependence on fossil fuels.

In the United States, however, the public perception of nuclear energy is less than favorable. There are formidable disadvantages, including the creation of radioactive wastes and the possibility of an accident that would release radioactive substances into the environment. In rebuttal, advocates point out that we cannot insist that nuclear fission energy be absolutely safe while at the same time accept hazards such as tanker spills, offshore drilling, global warming, acid rain, and coal miners' diseases.

To date, no long-term repositories for spent nuclear fuel rods are in operation anywhere in the world, primarily because few, if any, communities want such a repository in their “backyard.” Furthermore, once a potential site gets chosen, extensive and time-consuming evaluations are necessary. For example, tests at a promising site beneath Yucca Mountain in Nevada, shown in **Figure 17.16**, began in 1982. Some 27 years later, in 2009, after \$8 billion worth of testing, this site was found to be unacceptable. Currently, spent nuclear fuel is typically stored at or close to the nuclear plant where it was generated.

In addition to generating radioactive wastes, nuclear power plants pose the risk of having an accident in which radioactive material is released into the environment. The safety design of a nuclear power plant, however, has great bearing on the risks associated with generating nuclear fission energy. In 1979, a nuclear reactor at a facility on Three Mile Island, near Harrisburg, Pennsylvania, heated to the point that the reactor core began



FOR YOUR INFORMATION

According to the World nuclear association, “during the next 50 years, as Earth’s population expands from 8 billion toward 10 billion, humanity will consume more energy than the combined total used in all previous history. With carbon emissions now threatening the stability of the biosphere, the security of our world requires a massive transformation to clean energy. ‘Renewables’ like solar, wind, and biomass can help. But only nuclear power offers clean, atmosphere-friendly energy on a massive scale.”



READING CHECK

Where is the location of the U.S. Long-term radioactive waste repository?

< Figure 17.16

Yucca Mountain in Nevada was a promising site for a permanent repository for nuclear wastes. Had the site been approved, it would have housed some 70,000 tons of radioactive wastes within a network of tunnels 150 kilometers in combined length.



(a)



(b)

^ Figure 17.17

(a) In 1986, a meltdown occurred at this nuclear power plant in Chernobyl, Ukraine. Because there was no containment building, large amounts of radioactive material were released into the environment. Three people died outright, and dozens more died from radiation sickness within a few weeks. Thousands who were exposed to high levels of radiation stand an increased risk of cancer. (b) The nearby town of Pripyat was evacuated and remains abandoned decades later due to high levels of radiation. (Photo: Carl Montgomery)



FOR YOUR INFORMATION

What of batteries powered by nuclear wastes? Such batteries would run continuously, with no need of recharging. Such is the mission of the Nano Diamond Battery. To learn more, explore, <https://ndb.technology>.



to melt. No appreciable radioactivity leaked into the environment, because the core was housed in a containment building (as shown in Figure 5.26). Seven years later, in 1986, a total meltdown occurred at the nuclear power plant shown in **Figure 17.17**, the Chernobyl plant in what is now Ukraine. Notably, the reactor core of the Chernobyl plant was not built and did not operate in accordance with internationally accepted nuclear safety principles. For example, the medium used to control the fission reactions was graphite, which loses its ability to control the reactions as the core temperature rises. Also, the reactor was not housed in a containment building. Because there was no containment building, large amounts of radiation escaped into the environment.

In March 2011, a powerful 9.0 earthquake off the coast of Japan resulted in a massive tsunami 15 m in height (49 feet). The operating nuclear reactors of the Fukushima Daiichi nuclear power plant along the coast of Japan were promptly shut down after the earthquake. The core of any nuclear reactor, however, takes many days to cool upon being shut down. Thus, pumps are needed to pass cooling water over the reactor. The operation of these pumps requires electricity, which comes from the power grid, or in a blackout, from a set of on-site diesel electric generators. Unfortunately, the tsunami that came 50 minutes after the earthquake severed the plant's connection to the grid. Furthermore, the emergency generators were located in the lower levels, which were promptly flooded as the tsunami waves passed over the plant's 5.7 m (19 feet) high seawalls. The result was a deadly nuclear disaster (**Figure 17.18**).

Without power for the cooling system, the Fukushima reactors experienced a full meltdown, which means the uranium fuel turned into a molten phase and dropped to the floor of the containment building. By the next day, however, firefighter crews were able to pump seawater into the containment buildings in an effort to stop the ongoing meltdown. Because of their efforts, less than a meter of the 7-m thick concrete floor was penetrated by the meltdown material, which is to say that most of the radioactivity was contained.



< **Figure 17.18**

Two workers at the Fukushima nuclear power plant died soon after the power station was crippled. Others bravely stayed to help manage the disaster despite high levels of radiation. Across Japan, the earthquake and tsunami directly killed about 20,000 people.

The worst-case scenario would have occurred had the melted fuel penetrated the floor. In such a case, there would have been a massive leak of highly radioactive material into the environment. Radiation, however, was released from the venting of gases and the release of coolant. The extent of this radiation release is estimated to be about 10 percent of the Chernobyl meltdown. At both of these facilities, the efforts to clean up and contain the radioactive wastes will last for many decades.

Recent technological advances hold the promise of increased safety. Early reactors rely on a series of active measures, such as water pumps, that come into play to keep the reactor core cool in the event of an accident. A major drawback is that these safety devices are subject to failure, as was evident at Fukushima. The Generation IV reactor designs discussed in Chapter 5 provide what is called passive stability, in which natural processes such as evaporation are used to keep the reactor core cool. Furthermore, the core has a negative temperature coefficient, which means the reactor shuts itself down as its temperature rises owing to a number of physical effects, such as any swelling of the control rods.

The percentage of the world’s electricity produced by fission reactors in 2010 stood at about 15 percent. By 2020 this had dropped to about 10 percent, the difference being picked up by renewable energy sources, most notably wind (**Figure 17.19**).

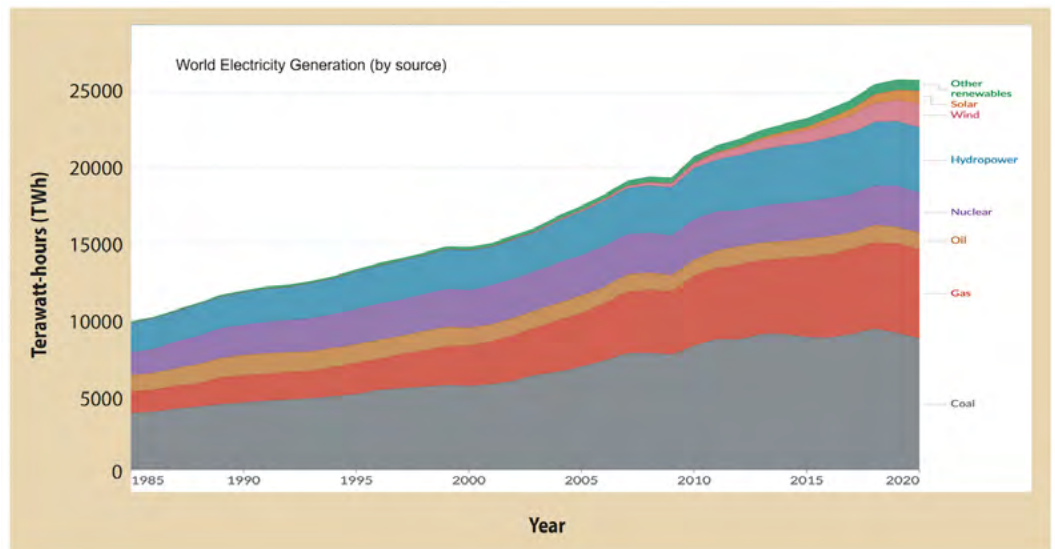
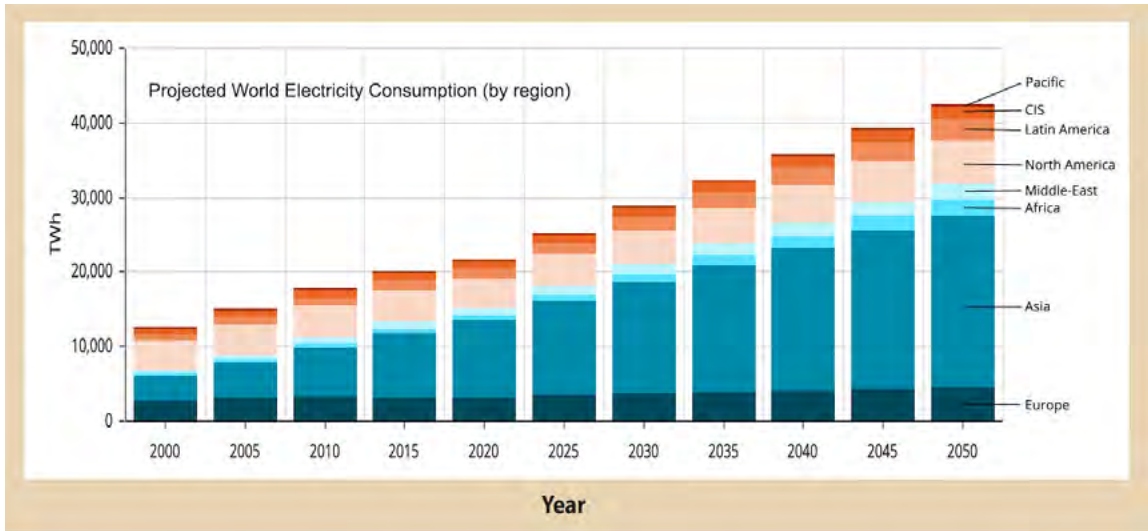


Figure 17.19 >

World electricity generation by source of energy from 1985 to 2020. (Source: BP Statistical Review)



^ Figure 17.20

Total worldwide electricity consumption projected through 2050. Note the greatest expansion is set to occur in Asia, which represents over half the world population and yet where the majority of people currently remain underserved. (Source: EnerData)

Ideally, renewables will continue to edge their way into the scene to help meet growing energy demand. At issue, however, is that this demand is set to grow significantly, as shown in **Figure 17.20**. If new nuclear power plants are not built, will renewables be able to keep up with this demand? If not, the only alternative would be to build additional fossil fuel power plants.

CONCEPT CHECK

What is the major disadvantage of nuclear fission as an energy source?

CHECK YOUR ANSWER Nuclear fission reactors generate large amounts of radioactive wastes that require permanent large-scale storage facilities.