

Chapter 3:

Non-renewable Energy



An illustration of fossil fuel extraction and use: a truck transporting materials at an oil mining site and cooling towers releasing steam at a power plant. Source: AI generated.

Learning Outcomes

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

1. List specific examples of non-renewable energy sources
2. Explain what makes an energy source non-renewable
3. Describe the main types of fossil fuels and how they formed
4. Explain the environmental impacts associated with exploration, extraction and use of the different types of fossil fuels
5. Explain nuclear energy, how it works, its benefits and risks

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3.1 What is Energy?

Energy is the ability of a system to do work. A system has done work if it has exerted a force on another system over some distance. When this happens, energy is transferred from one system to another. At least some of the energy is also transformed from one type to another during this process. One can keep track of how much energy transfers into or out of a system. There are two categories that all energy falls into: kinetic and potential. **Kinetic energy** refers to types of energy associated with motion (**Figure 3.1**, top). For example, a rock rolling down a hill, the wind blowing through trees, water flowing over a dam, and a cyclist riding a bicycle are just a few examples of kinetic energy. **Potential energy** is energy possessed by an object or system due to its position in space relative to another object or system and forces between the two (**Figure 3.1**, bottom). Examples include a rock poised at the top of a hill and water stored behind a dam. Some forms of energy are part kinetic and part potential energy. **Chemical energy** describes the *potential* of a chemical substance to undergo a chemical reaction and transform other chemical substances; hence it is a form of potential energy. Examples include energy stored in the food you eat and the gasoline that you put in your car.



Examples of different forms of **kinetic** energy



Examples of different forms of **potential** energy

Figure 3.1: Examples kinetic (top) and potential (bottom) forms of energy. *All images were obtained from Wikimedia commons (public domain).*

Living organisms need energy to perform life-sustaining “work” in order to survive. For nearly all living systems on Earth, the sun is the ultimate source of that energy. Over time, we humans have developed an understanding of energy that has allowed us to harness it for

uses well beyond basic survival. The development and evolution of human society is largely attributed to our relationship with energy. The first major advancement in human understanding of energy was the mastery of fire for cooking and heating. Modern civilization is especially dependent on energy and some of its most distinct characteristics such as population growth, environmental impact and climate change are all a consequence of energy use. We use energy to heat and light our homes; power our machinery; fuel our vehicles; produce plastics, pharmaceuticals, and synthetic fibers; and provide the comforts and conveniences to which we have grown accustomed in the industrial age. Societal complexity, affluence, and the gap between poor and rich peoples are all directly related to our level of energy consumption.



Test your knowledge...

- 1) What are the two types of energy?
- 2) Which type of energy are each of the following: electricity, blowing wind, heat, cheeseburger, diesel fuel, sunlight, a compressed spring, stretched rubber band, flowing river

3.2 Fossil Fuels

Fossil fuel is the term given to an energy source that has a high **hydrocarbon** content (see Chapter 1 for a review of hydrocarbon molecules), is found in the Earth's crust, formed in the geologic past, and can be burned easily to release energy. Fossil fuels were formed from prehistoric plants and animals that lived hundreds of millions of years ago (100 – 500 million years ago). When these ancient living organisms died they were quickly buried and subjected to immense pressure from overlying earth materials including layers of mud, rock, sand, and sometimes surface water bodies such as oceans and lakes.

During the millions of years that passed, the dead plants and animals slowly decomposed in **anaerobic** (very low to no oxygen) conditions and their chemical energy became concentrated. The organic compounds that once made up tissues of these organisms were chemically changed under high pressures and temperatures over time. While some fossil fuels are likely in the process of formation today, the amount of time required for usable quantities to form is measured in millions of years, so these fuels will never be available for us. Thus, for all practical purposes we consider fossil fuels to be finite and a **non-renewable resource**.

3.2.1 Fossil Fuel Types and Formation

There are three main types of fossil fuels – natural gas, oil, and coal – and the specific type formed depends on the combination of organic matter that was present, how long it was buried and what temperature and pressure conditions existed when they were decomposing.

Oil and **natural gas** were created from organisms that lived in water and were buried under ocean or river sediments. Long after the great prehistoric seas and rivers vanished, heat, pressure, and bacteria combined to compress and transform the organic material under layers of silt or shale rock (**Figure 3.2**). In most areas, a thick liquid called oil formed first, but in deeper, hot regions underground, the transformation process continued until natural gas was formed. Over time, some of this oil and natural gas began working its way upward through the earth's crust until they ran into rock formations called “**caprocks**” that are dense enough to prevent them from seeping to the surface. It is from under these caprocks that most oil and natural gas is retrieved today.

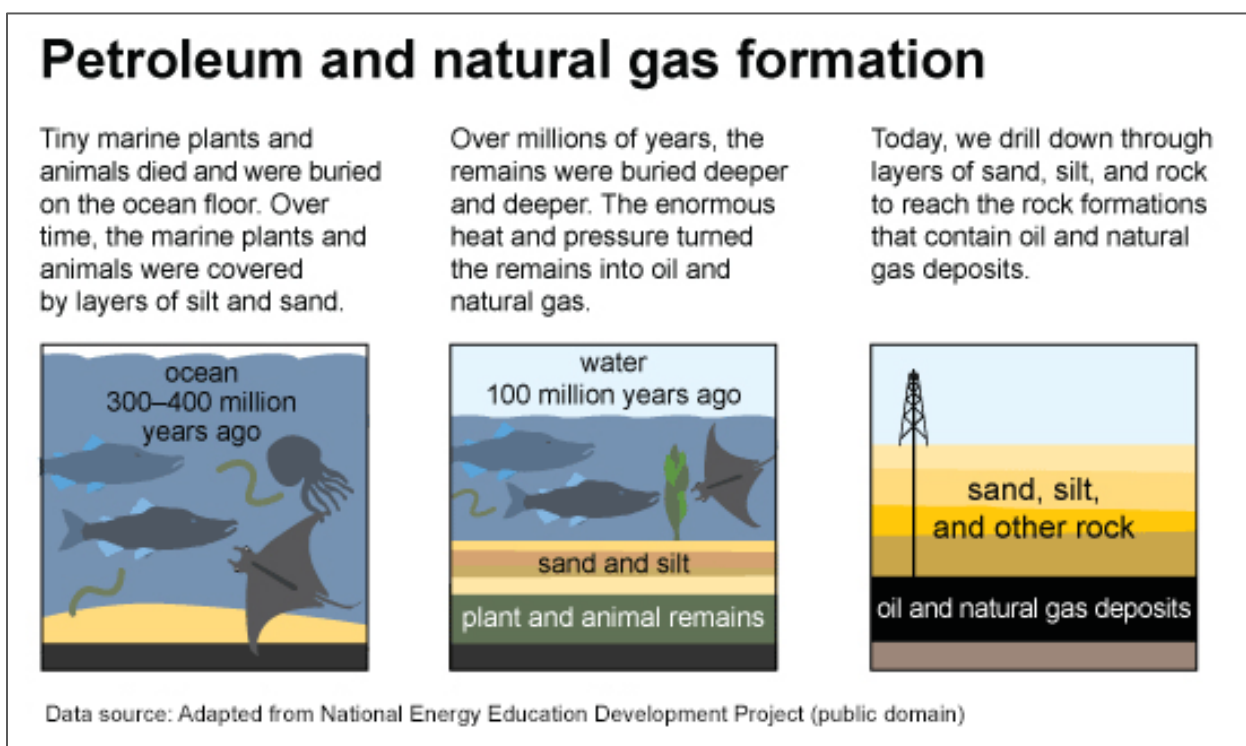


Figure 3.2: Oil and natural gas (petroleum) formation. Source: U.S. Energy Information Administration. <https://www.eia.gov/energyexplained/natural-gas/>

Coal is a fossil fuel that formed from the remains of trees, ferns, and other plants that lived 300 to 400 million years ago (**Figure 3.3**). In some areas, such as portions of what is now the eastern United States, coal was formed from swamps covered by sea water. The sea water contained a large amount of sulfur, and as the seas dried up, the sulfur was left behind in the coal. Scientists are working on ways to take the sulfur out of coal because when coal burns, the sulfur is released in to the atmosphere as an air pollutant (see Chapter

5). Some coal deposits, however, were formed from freshwater swamps which had very little sulfur in them. These coal deposits are located largely in the western part of the United States.

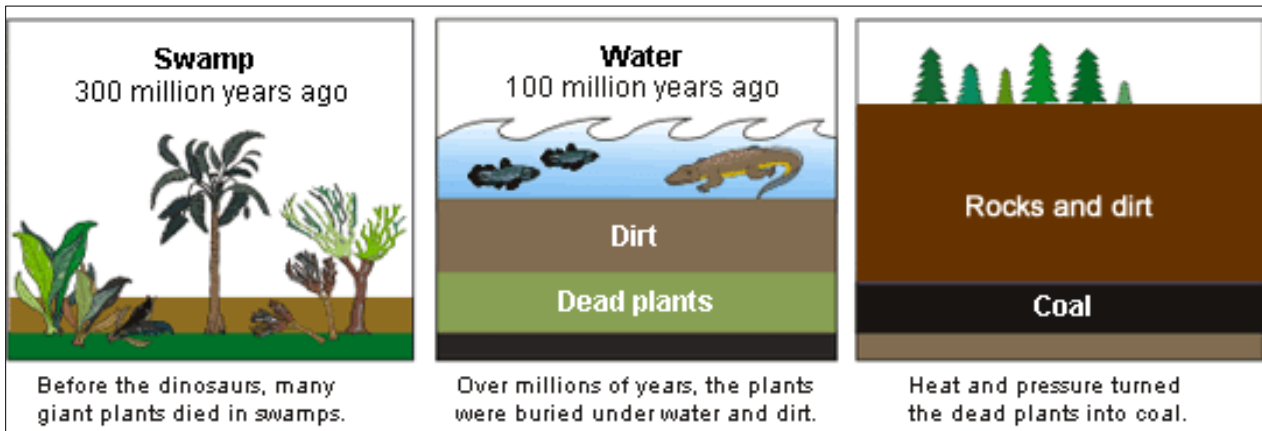


Figure 3.3: The process of coal formation. **Source:** U.S. Energy Information Administration.

3.2.2 Fossil Fuel Consumption Patterns

Historically, human prosperity has been directly correlated with energy use. The health and vitality of world societies critically depends on energy, most of which comes from fossil fuels (**Figure 3.4**). Energy resources, however, are unevenly distributed throughout the world, and so are the consumption rates. Developed regions generally consume far more energy than the developing regions. For example, the United States has only about 5% of the world's population but constitutes over 20% of the world's energy consumption. Additionally, developing countries devote a larger proportion of energy consumption to subsistence activities such as growing and preparing food, and heating homes. Industrialized nations rely more on mechanized equipment and technology and, therefore, a greater proportion of their energy consumption goes to transportation and industry.

Fossil fuels can be utilized without being converted or transformed to another form of energy, this is referred to as **primary energy** consumption. In their primary form, fossil fuels can be used for transportation, heating and cooking, or used to generate electricity. The use of **electricity** is a form of **secondary energy** consumption. Transforming fossil fuel energy into electricity allows for easier transportation over long distances and application to a variety of uses. Additionally, there are four major sectors that consume energy: 1) The *industrial sector* which includes facilities and equipment used for manufacturing, agriculture, mining, and construction; 2) The *transportation sector* includes vehicles that transport people or goods including cars, trucks, buses, motorcycles, trains, aircraft, boats, barges, and ships; 3) The *residential sector* consists of homes and apartments; 4) The *commercial sector* includes offices, malls, stores, schools, hospitals, hotels, warehouses, restaurants, places of worship, and more. Each of these sectors also consumes electricity produced by the electric power sector.

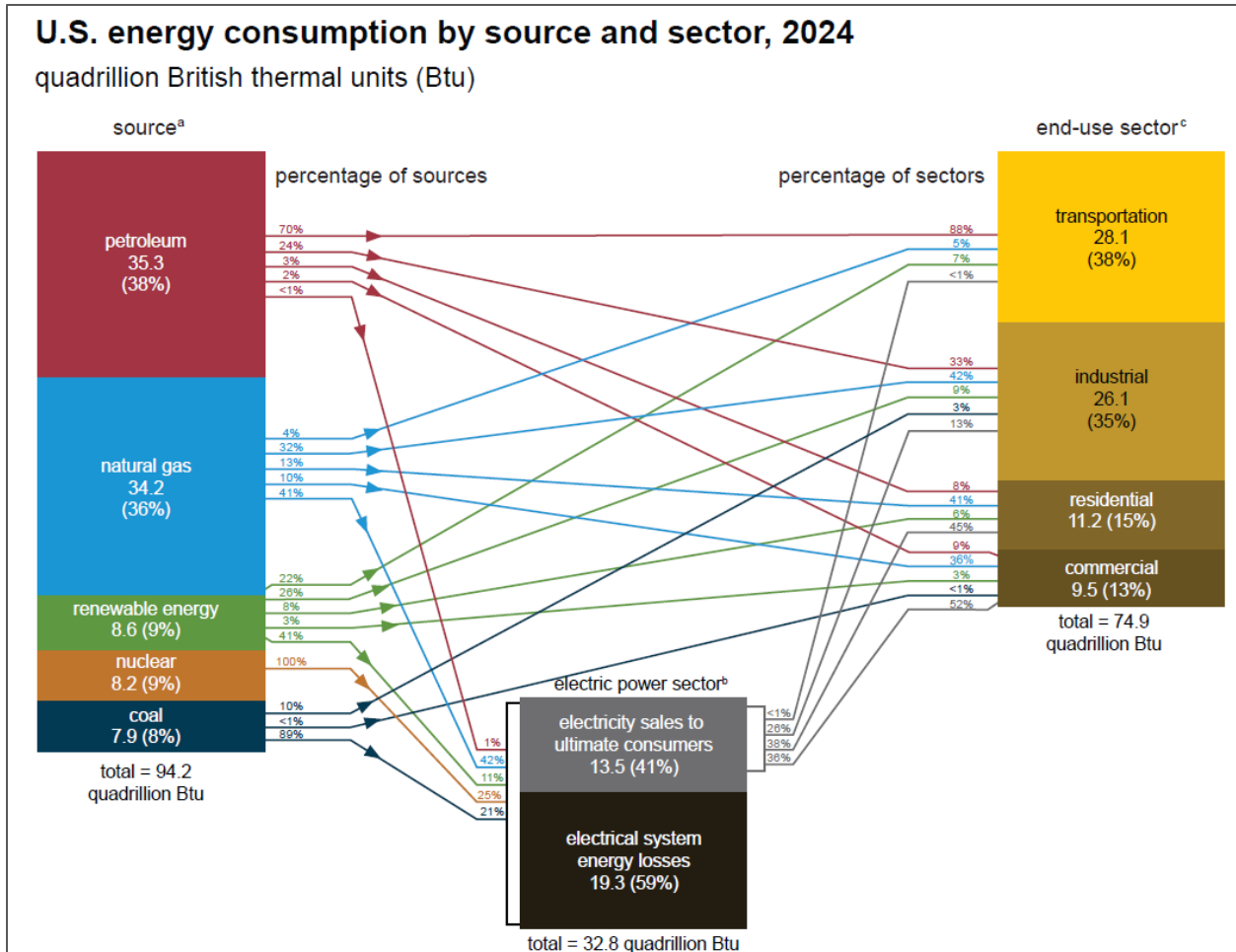


Figure 3.4: U.S. primary energy consumption by source and sector 2024, showing that about 80 % of energy consumption comes from fossil fuels. Data from U.S. Energy Information Administration, <https://www.eia.gov/totalenergy/data/monthly/> .



Test your knowledge...

1. What are fossil fuels? What's their chemical composition?
2. _____ primarily formed from the remains of marine organisms in deep oceans whereas _____ originated from plant material in ancient swamps.
3. Is it primary or secondary energy consumption? i) driving a fully electric vehicle, ii) using a gas grill, iii) charging a laptop computer, iv) using coal to produce electricity

3.3 Coal

Coal is a combustible black or brownish-black sedimentary rock with a high amount of carbon and hydrocarbons. Coal is classified into four main types, or ranks depending on the types and amounts of carbon present and on the amount of heat energy the coal can produce, including anthracite, bituminous, subbituminous, and lignite (highest to lowest ranked, pictured in **Figure 3.5**). For us to use the potential energy stored in coal, it first must be mined from the ground. This process in itself uses a great deal of resources and has its own environmental impacts. Coal then typically undergoes processing to make it suitable for use in **coal-fired power plants**. Finally, the processed coal is burned in these power plants, and the kinetic energy released from its combustion is harnessed for electricity generation or other purposes. We will investigate each of these steps individually below.

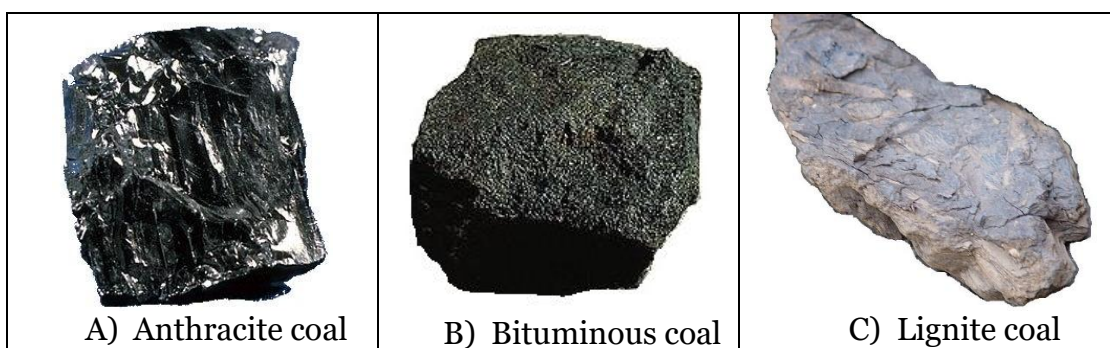


Figure 3.5: Different types of coal. Images obtained from Wikimedia Commons.

3.3.1 Coal Mining and Processing, and Electricity Generation

There are two primary methods of coal mining: **strip mining** and **underground mining**. Strip-, or surface-, mining uses large machines to remove the soil and layers of rock known as **overburden** to expose coal seams. It is typically used when the coal is less than 200 feet underground. **Mountaintop removal** is a form of surface mining where the tops of mountains are blasted with dynamite and removed to access coal seams. After the mining is finished, the disturbed area can be re-covered with topsoil, and the area is replanted. However, the topography of the mountain is permanently altered.

Underground mining, sometimes called deep mining, is used when the coal is several hundred feet below the surface. Some underground mines are thousands of feet deep, and extend for miles. Miners ride elevators down deep mine shafts and travel on small trains in long tunnels to get to the coal. The miners use large machines that dig out the coal.

Once mined, coal may go to a preparation plant located near the mining site where it is cleaned and processed to remove impurities such as rocks and dirt, ash, sulfur, and other unwanted materials. This process increases the amount of energy that can be obtained from a unit of coal, known as its **heating value**.

Finally, the mined and processed coal must be transported. Transportation can be more expensive than mining the coal. Nearly 70% of coal delivered in the United States is transported, for at least part of its trip, by train. Coal can also be transported by barge, ship,

or truck. Coal can also be crushed, mixed with water, and sent through a slurry **pipeline**. Sometimes, coal-fired electric power plants (**Figure 3.6**) are built near coal mines to lower transportation costs.

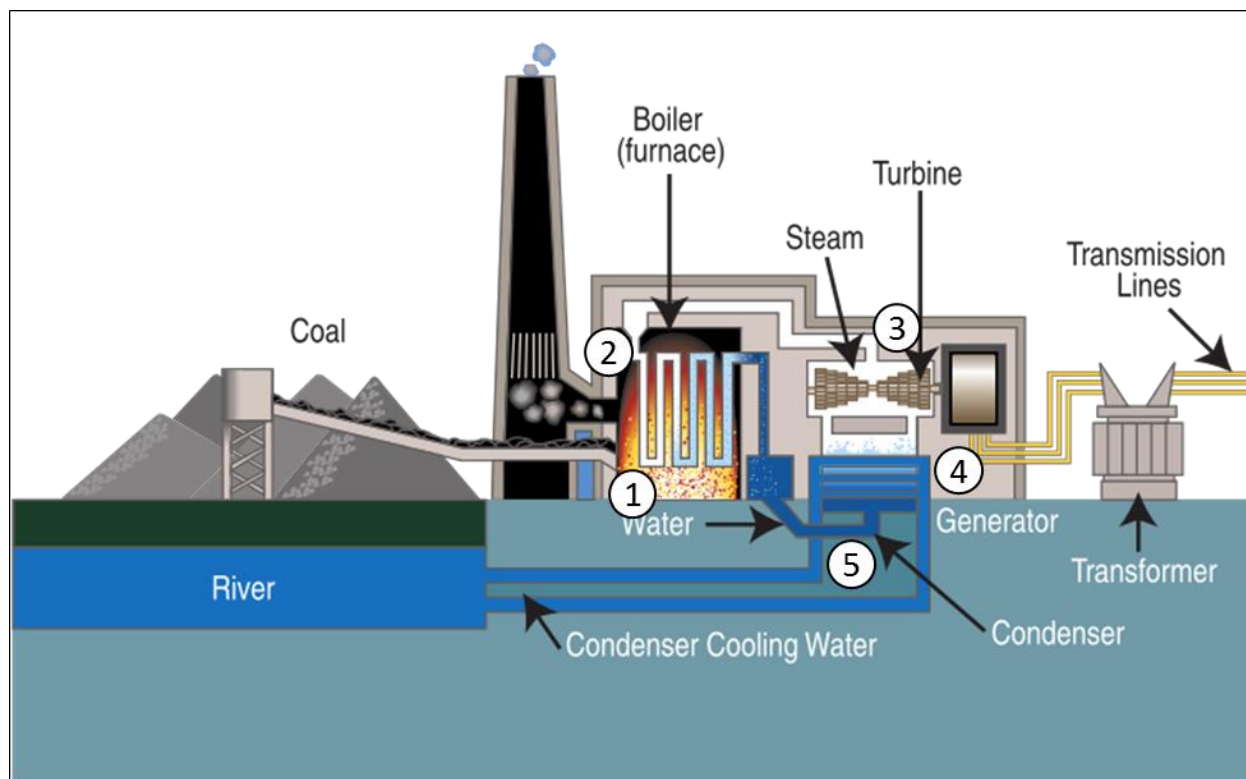
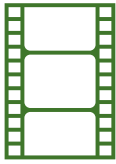


Figure 3.6: Diagram of a typical steam-cycle coal power plant. Image by US Tennessee Valley Authority – Public domain. www.tva.com. Numbers in this figure correspond to numbers in the above paragraph of text.

Once at the power plant coal is first pulverized into a fine powder to allowing for the most complete combustion possible. The pulverized coal is then mixed with hot air and blown into a **furnace** (see step 1 in **Figure 3.6**). Purified water, pumped through pipes inside a **boiler**, is turned into steam by the heat from the combustion of coal (step 2 in **Figure 3.6**). The high pressure of the steam pushing against a series of giant **turbine** blades turns the turbine shaft (step 3 in **Figure 3.6**). The turbine shaft is connected to the shaft of the **generator**, where magnets spin within wire coils to produce electricity (step 4 in **Figure 3.6**). After doing its work in the turbine, the steam is drawn into a **condenser**, a large chamber in the basement of the power plant (step 5 in **Figure 3.6**). In this important step, millions of gallons of cool water from a nearby source (such as a river or lake) are pumped through a network of tubes running through the condenser. The cool water in the tubes converts the steam back into water that can be used over and over again in the plant. The cooling water is returned to its source without any contamination except at a higher temperature than when first extracted from the river or lake. **Figure 3.6** is a schematic diagram showing a typical layout of a coal-fire power plant. You can also watch a short video of a virtual tour of a coal power plant at the URL provided below.



Follow this link for a virtual tour of a coal power plant

<https://www.youtube.com/watch?v=2IKECt4Y3RI>

3.3.2 Health and Environmental Impacts of Coal Mining

A majority of the coal mined in the United States (about 66%) is from surface, or strip mines which leave highly visible impacts at the surface (**Figure 3.7**). Strip mining operations generally involve removing soils, rock, and other material to access shallow deposits of coal and therefore leave permanent scars on the landscape. It also involves the destruction of substantial amounts of forests and other ecosystems, destroying natural habitats and threatening **biodiversity**.

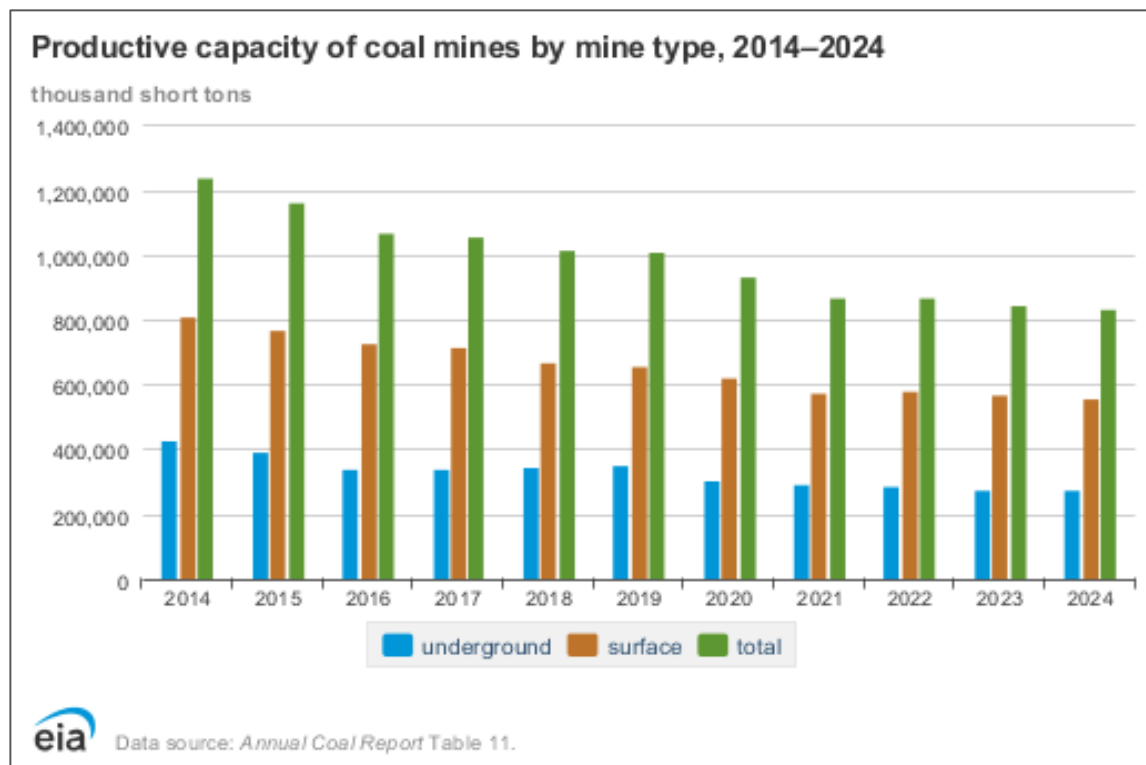


Figure 3.7: Productive capacity of coal mines by mine type, 2014-2024. Image from the US Energy Information Administration 2025 Annual Coal Report. <https://www.eia.gov/coal/annual/>.

Mountaintop removal, the extreme form of strip mining, has affected large areas of the Appalachian Mountains in West Virginia and Kentucky. The tops of mountains are removed using a combination of explosives and mining equipment and the material is deposited into nearby valleys. This technique not only alters the landscape (**Figure 3.8**) but affects the health and quality of nearby streams by depositing rocks, dirt, and pollutants that can harm aquatic wildlife. While mountaintop removal mining has existed since the 1970s, its use

became more widespread and controversial beginning in the 1990s. U.S. laws require that dust and water runoff from areas affected by coal mining operations be controlled, and that the area be **reclaimed**, and returned to close to its original condition.

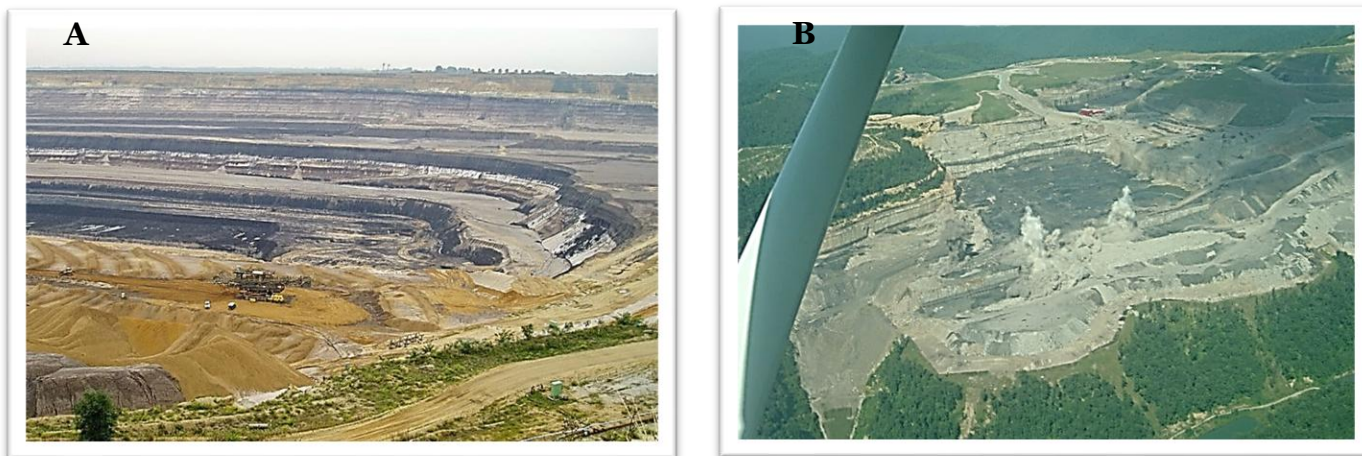


Figure 3.8: A) Strip mine for lignite coal at Garzweiler near Köln, Germany. Image from Wikimedia commons <https://commons.wikimedia.org/wiki/File:Garzweiler.strip.mine.jpg> B) Mountaintop removal in Eunice, WV, photo by Roston, obtained from <https://commons.wikimedia.org/wiki/File:Euniceblast3.JPG>

One of the largest environmental impacts of underground mining may be the **methane** (CH_4) gas that must be vented out of mines to make the mines a safe place to work. Methane is a **greenhouse gas**, meaning that it enhances the greenhouse effect naturally occurring in our atmosphere, and contributes to global warming and global climate change. Its global warming potential, or relative capacity to produce the greenhouse effect, is higher than that of carbon dioxide (see Chapter 6). Other impacts of underground mining include ground collapse above mine tunnels, draining of acidic water from abandoned mines into nearby streams and black lung disease. Acidic water lowers the pH (resulting in increased acidity), which is detrimental to aquatic organisms. This **acid mine drainage** is an environmental impact associated with both underground mining and strip mining.

Black lung disease is a chronic occupational illness caused by long-term inhalation of coal dust in underground or surface mining environments. The fine coal particles accumulate in the lungs, leading to inflammation, scarring (fibrosis), and reduced lung function. Symptoms often include chronic cough, shortness of breath, and fatigue. In severe cases, the disease can progress to massive fibrosis, respiratory failure, and increased susceptibility to infections. Black lung is preventable through proper dust control measures, ventilation systems, and use of protective equipment, but it remains a significant health risk for coal miners worldwide.

3.3.3 Health and Environmental Impacts of Coal Burning

In the United States and most of the world, most of the coal consumed is used as a fuel to generate electricity. Burning coal produces emissions such as **sulfur dioxide** (SO_2) and

nitrogen oxides (NO_x) that are associated with acid rain (more on this in Chapter 5). These emissions are also the cause of various illnesses such as respiratory diseases (also discussed in chapter 5) **Carbon dioxide** (CO₂), another emission resulting from burning coal, is a major greenhouse gas that is associated with global warming (see Chapter 6).

Ash (including fly ash and bottom ash) is a residue created when coal is burned at power plants. In the past, fly ash was released into the air through the smokestack, where it would contribute to **particulate matter** air pollution (see Chapter 5). Laws now require that much of the fly ash now must be captured by pollution control devices, like scrubbers. In the United States, fly ash is generally stored at coal power plants or placed in landfills. Pollution leaching from ash storage and landfills into groundwater and the rupture of several large impoundments of ash are environmental concerns.

Coal is the largest source of **mercury** and also a source of other **heavy metals**, many of which have been linked to both neurological and developmental problems in humans and other animals. Mercury concentrations in the air usually are low and of little direct concern. However, when mercury enters water, either directly or through deposition from the air, biological processes transform it into **methylmercury**, a highly toxic chemical that **bioaccumulates** in fish and the animals (including humans) that eat fish, as animal bodies lack sufficient excretion pathways for this chemical. This means that the concentration of methylmercury will typically increase through an individual's lifetime if it is present in their food. Methylmercury also

biomagnifies in aquatic food chains, meaning that animals at higher trophic levels typically contain more methylmercury than animals at lower trophic levels. Biomagnification is further explained in **Figure 3.9**.

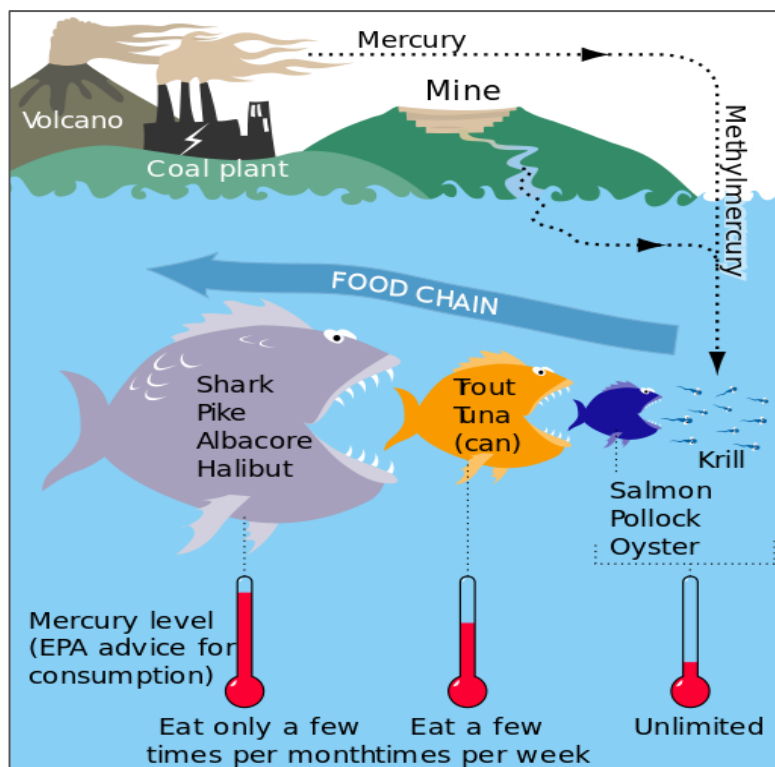


Figure 3.9. Biomagnification of mercury in an aquatic ecosystem. Mercury emitted from natural (e.g., volcano) or anthropogenic (e.g., coal plant) sources is converted into methylmercury in the environment. Methylmercury is highly toxic on its own, and has the ability to both bioaccumulate and biomagnify within an ecosystem. This figure also shows EPA recommended consumption guidelines for some types of fish based on mercury consumption. These guidelines are most important for children, pregnant women, nursing mothers, and women who may become pregnant in the future (credit: Bretwood Higman).

3.3.4 Reducing the Environmental Impacts of Coal Use

Regulations such as the **Clean Air Act** and the **Clean Water Act** require industries to reduce pollutants released into the air and water. Below are some actions that have been taken to reduce the negative impacts of coal on human and environmental health:

- **Clean coal technology:** Industry has found several ways to reduce sulfur, NO_x, and other impurities from coal before burning.
- Coal consumers have shifted toward greater use of low sulfur coal.
- Power plants use **scrubbers**, to clean SO₂, NO_x, particulate matter, and mercury from the smoke before it leaves their smokestacks. In addition, industry and the U.S. government have cooperated to develop technologies that make coal more energy-efficient so less needs to be burned.

Research is ongoing to address emissions of carbon dioxide from coal combustion. **Carbon capture & sequestration** (CCS) separates CO₂ from emissions sources and recovers it in a concentrated stream. The CO₂ can then be sequestered, which puts CO₂ into storage, possibly underground, where it will remain permanently (see Chapter 6).

Reuse and recycling can also reduce coal's environmental impact. Land that was previously used for coal mining can be reclaimed and used for airports, landfills, and golf courses. Waste products captured by scrubbers can be used to produce products like cement and synthetic gypsum for wallboard.



Test your knowledge...

- 1) Coal is mainly used _____
- 2) List two major environmental impacts of coal mining
- 3) List two approaches for reducing the environmental impacts of burning coal
- 4) T/F Burning coal is a major source of sulfur dioxide, which contributes to acid rain
- 5) Acid mine drainage is an environmental impact resulting from burning coal

3.4 Oil

Petroleum oil is currently the most widely used fossil fuel and accounts for about one third of global energy consumption. Unlike coal, which is primarily used as a fuel for electricity generation, oil is primarily used as a fuel for **transportation**. Oil is also used to manufacture **plastics** and other synthetic compounds ubiquitous to our everyday life.

Crude (unprocessed) oil varies greatly in appearance depending on its composition. It is usually black or dark brown (although it may be yellowish, reddish, or even greenish). In the reservoir it is usually found in association with natural gas, which being lighter forms a

gas cap over the oil. Oil is made up of hydrocarbons which are molecules that contain hydrogen and carbon in various lengths and structures, from straight chains to branching chains to rings. Hydrocarbons contain a lot of energy and many of the things derived from crude oil like gasoline, diesel fuel, paraffin wax and so on take advantage of this energy.

3.4.1 Conventional Drilling

Oil is mainly obtained by drilling either on land (**onshore**) or in the ocean (**offshore**) (**Figure 3.10**). Early offshore drilling was generally limited to areas where the water was less than 300 feet deep. Oil and natural gas drilling rigs now operate in water as deep as two miles. Floating platforms are used for drilling in deeper waters. These self-propelled vessels are attached to the ocean floor using large cables and anchors. Wells are drilled from these platforms which are also used to lower production equipment to the ocean floor. Some drilling platforms stand on stilt-like legs that are embedded in the ocean floor. These platforms hold all required drilling equipment as well as housing and storage areas for the work crews.



Figure 3.10. Offshore (left) oil platform in Green Canyon, Gulf of Mexico (credit: [Guava Train](#)); pumpjack-style onshore oil rig (right) belonging to California oil and gas program (Photo by Bob Wick, BLM).

Offshore oil producers are required to take precautions to prevent pollution, spills, and significant changes to the ocean environment. Offshore rigs are designed to withstand hurricanes. Offshore production is much more expensive than land-based production. When offshore oil wells are no longer productive enough to be economical, they are sealed and abandoned according to applicable regulations.

Oil harvested from both offshore and onshore operations must be sent to consumers. Additionally, oil is heavily traded on the international market. Oil can be transported long distances by tanker ship over water, or by pipeline over land (**Figure 3.11**). Both of these have the potential for leaks and/or spills (see Section 3.4.4).



Figure 3.11. The Trans-Alaska Pipeline, which runs from the approximately 800 miles from the Arctic Ocean to the Gulf of Alaska at Valdez. Credit: Luca Galuzzi.

3.4.2 Processing and Refining

When extracted, crude oil consists of many types of hydrocarbons as well as some unwanted substances such as sulfur, nitrogen, oxygen, dissolved metals, and water all mixed together. Unprocessed crude oil is therefore, not generally useful in industrial applications and must first be separated into different useable products at a **refinery** (**Figure 3.12**). All refineries perform three basic steps: separation, conversion, and treatment in the processing and refining of crude oil.

During **separation**, the various products (hydrocarbons) are separated into different components (called *fractions*), by taking advantage of the differences in boiling temperature of the components. This process is called *fractional distillation* and involves heating up the crude, letting it vaporize and then condensing the vapor. The lightest components have the lowest boiling temperature and rise to the top while the heaviest which also have the highest boiling temperature remain at the bottom.

Conversion is the chemical processing in which some of the fractions are transformed into other products, for example, a refinery can turn diesel fuel into gasoline depending on the demand for gasoline. Conversion can involve breaking larger hydrocarbon chains into smaller ones (cracking), combining smaller chains into larger ones (unification) or rearranging the molecules to create desired products (alteration).

Treatment is done to the fractions to remove impurities such as sulfur, nitrogen and water among others. Refineries also combine the various fractions (processed and unprocessed) into mixtures to make desired products. For example, different mixtures of hydrocarbon chains can create gasolines with different octane ratings, with and without

additives, lubricating oils of various weights and grades (e.g., WD-40, 10W-40, 5W-30, etc.), heating oil and many others. The products are stored on-site until they can be delivered to various markets such as gas stations, airports and chemical plants.



Figure 3.12: Tesoro Corporation Oil Refinery in Anacortes, Washington. Photo by Walter Siegmund. https://commons.wikimedia.org/wiki/Oil_refinery#/media/File:Anacortes_Refinery_31904.JPG

A 42 U.S. gallon barrel of crude oil yields about 45 gallons of petroleum products because of refinery processing gain. This increase in volume is similar to what happens to popcorn when it is popped. Gasoline makes up the largest fraction of all petroleum products obtained (**Figure 3.13**). Other products include diesel fuel and heating oil, jet fuel, petrochemical feedstocks, waxes, lubricating oils, and asphalt.

3.4.3 Fracking For Oil

Hydraulic fracturing, informally referred to as “fracking,” is an oil well development process that typically involves injecting water, sand, and chemicals under high pressure into a bedrock formation via the well. This process is intended to create new fractures in the rock as well as increase

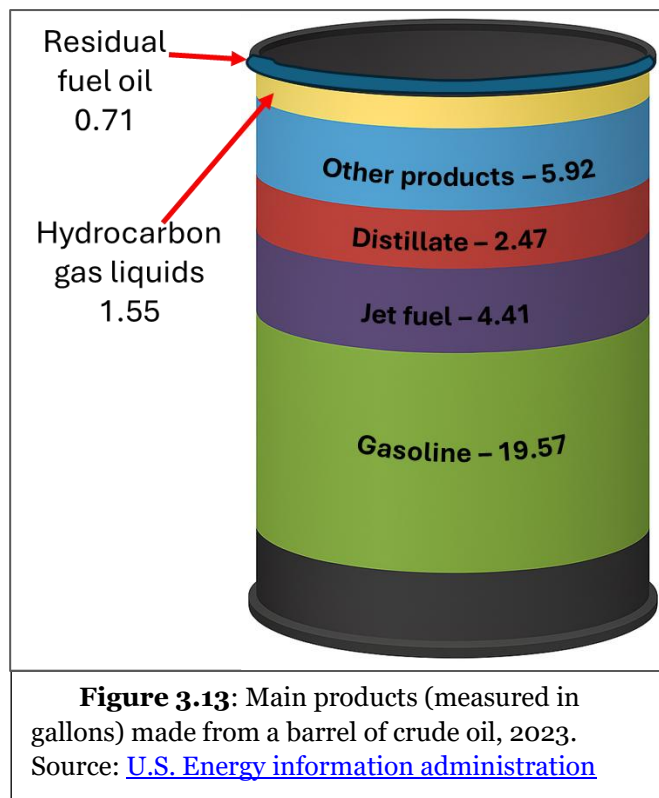


Figure 3.13: Main products (measured in gallons) made from a barrel of crude oil, 2023. Source: [U.S. Energy information administration](https://www.eia.gov)

the size, extent, and connectivity of existing fractures. Hydraulic fracturing is a well-stimulation technique used commonly in low-permeability rocks like tight sandstone, shale, and some coal beds to increase oil flow to a well from petroleum-bearing rock formations (**Figure 3.14**).

Energy development often requires substantial amounts of water, and hydraulic fracturing is no exception. Water is needed not only for the traditional drilling process, but also for the actual fracturing as well. Water is first mixed with chemicals and fine sands, then pumped at extremely high pressure into the shale rock to fracture it, forming pathways for the oil and gas to reach the well. The water is then recovered, along with the oil and gas.

There are concerns regarding the potential contamination of fresh groundwater resources from oil and gas extraction wells that use hydraulic fracturing; either from the petroleum resource being produced or from the chemicals introduced in the fracturing process. Fracking fluid flowback – the fluid pumped out of the well and separated from oil and gas – not only contains the chemical additives used in the drilling process but also contains heavy metals, radioactive materials, **volatile organic compounds (VOCs)** and hazardous air pollutants such as benzene, toluene, ethylbenzene and xylene. In some cases, this contaminated water is sent to water treatment plants that are not equipped to deal with some of these classes of contamination.

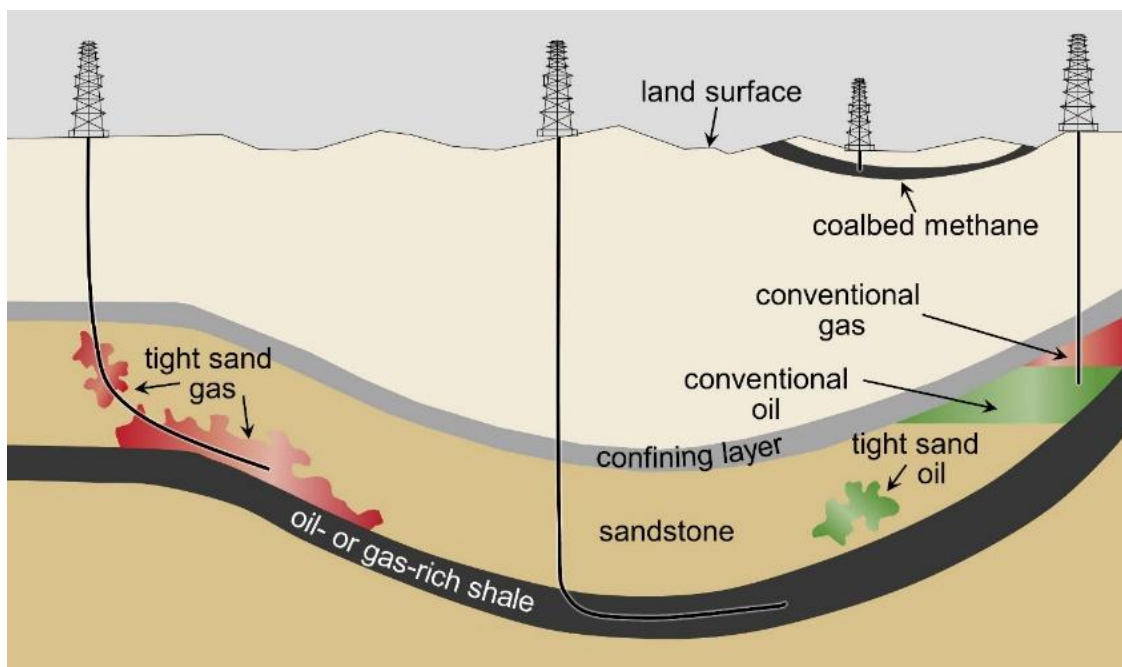


Figure 3.14: Schematic cross-section of general types of oil and gas resources and the orientations of production wells used in hydraulic fracturing. Source: US EPA (Public Domain)

3.4.4 Environmental Impacts of Oil

Burning petroleum oil products releases emission such as **carbon monoxide (CO)**, sulfur dioxide, nitrogen oxides, and particulate material all of which are air pollutants that

impact the environment as well as human health (see more on air pollution in Chapter 5). Petroleum also emits carbon dioxide which is a greenhouse gas.

Exploring and drilling for oil may disturb land and ocean habitats. On land, extensive infrastructure such as road networks, transport pipelines and housing for workers are needed to support a full-scale drilling operation. These can pollute soil and water, fragment habitats, and disturb wildlife.

Human-caused **oil spills** in rivers and oceans harm ecosystems. Natural oil seepages do occur and may be a significant source of oil that enters the environment globally, but they are slow, small, and spread out over large areas, and the ecosystem has adapted to them. Spills from tankers or well spills have more catastrophic impacts. The quantity of oil spilled during accidents has ranged from a few hundred tons to several hundred thousand tons but even small spills have been shown to have a great impact on ecosystems.

Oil spills at sea are generally much more damaging than those on land, since they can spread for hundreds of nautical miles in a thin oil slick which can cover beaches with a thin coating of oil. This can kill sea birds, mammals, shellfish and other organisms it coats. Oil spills on land are more readily containable if a makeshift earth dam can be rapidly bulldozed around the spill site before most of the oil escapes, and land animals can avoid the oil more easily. The amount of oil spilled from ships dropped significantly during the 1990s partly because new ships were required to have a double-hull lining to protect against spills.

Leaks also happen when we use petroleum products on land. For example, gasoline sometimes drips onto the ground when people are filling their gas tanks, when motor oil gets thrown away after an oil change, or when fuel escapes from a leaky storage tank. When it rains, the spilled products get washed into the gutter and eventually flow to rivers and into the ocean. Another way that oil sometimes gets into water is when fuel is leaked from motorboats and jet skis.

When a leak in a storage tank or pipeline occurs, petroleum products can also get into the ground, and the ground must be cleaned up. To prevent leaks from underground storage tanks, all buried tanks are supposed to be replaced by tanks with a double lining.



Test your knowledge...

1. Which energy sector uses the greatest (and which uses the least) proportion of oil?

2. Match the following processing steps of crude oil

- Separation *Adjusting product properties by mixing different streams to meet specifications*
- Conversion *Injecting high-pressure fluid into shale rock formations to release trapped oil*
- Blending *Transforming certain fractions into different products to meet demands (e.g. cracking)*
- Fracking *Removing impurities such as sulfur, nitrogen, and metals from fractions*
- Treatment *Dividing crude oil into fractions based on boiling points using distillation*

3.5 Natural Gas

Crude oil is frequently found in reservoirs along with natural gas. In the past, natural gas was either burned or allowed to escape into the atmosphere. Now, technology has been developed to capture the natural gas and either reinject it into the well or compress it into **liquid natural gas** (LNG).

Natural gas is predominately composed of methane (CH_4). Some of the gases that are produced along with methane, such as **butane** and **propane** (by-products), are separated and cleaned at a gas processing plant. The by-products, once removed, are used in a number of ways. For example, propane can be used for cooking on gas grills. Natural gas withdrawn from a well may contain liquid hydrocarbons and nonhydrocarbon gases. This is called **wet natural gas**. The natural gas is separated from these components near the site of the well or at a processing plant. Once the gas is entirely methane, it is then considered **dry natural gas** and is sent through pipelines to a local distribution company, and, ultimately, to the consumer.

A small amount of natural gas is shipped to the United States as LNG. We can also use machines called **digesters** that turn today's organic material (plants, animal wastes, etc.) into natural gas through the process of anaerobic decomposition. This process replaces waiting for millions of years for the gas to form naturally. The natural gas produced by

these digesters is not a fossil fuel but is rather a renewable source of bioenergy (see **Chapter 4**).

3.5.1 Fracking for Natural Gas

Conventional natural gas is found in permeable reservoirs, typically composed of sandstone or limestone, where extraction is relatively straightforward because the gas generally flows freely. Unconventional gas is found in rocks with extremely low permeability, which makes extracting it much more difficult. Such gas is extracted by employing so called “unconventional” techniques such as hydraulic fracturing (fracking), which has been in use since the late 1940s. In recent decades, fracking technology has greatly improved, and its use has been expanded. The process of fracking for gas is very similar to that of fracking for oil, and the environmental impacts are also similar (see **Section 3.3.3**).

As the use of hydraulic fracturing has increased within recent decades, so has the use of natural gas by the electrical generation and manufacturing industries. Most of the natural gas consumed in the United States is produced in the United States. Some is imported from Canada and shipped to the United States in pipelines. **Figure 3.15** shows the increase in dry natural gas production in the United States, and the resulting increase in natural gas consumption. Meanwhile, we are importing less natural gas as a country. Much of the increase in consumption is due to the construction of numerous natural gas power plants in recent years.

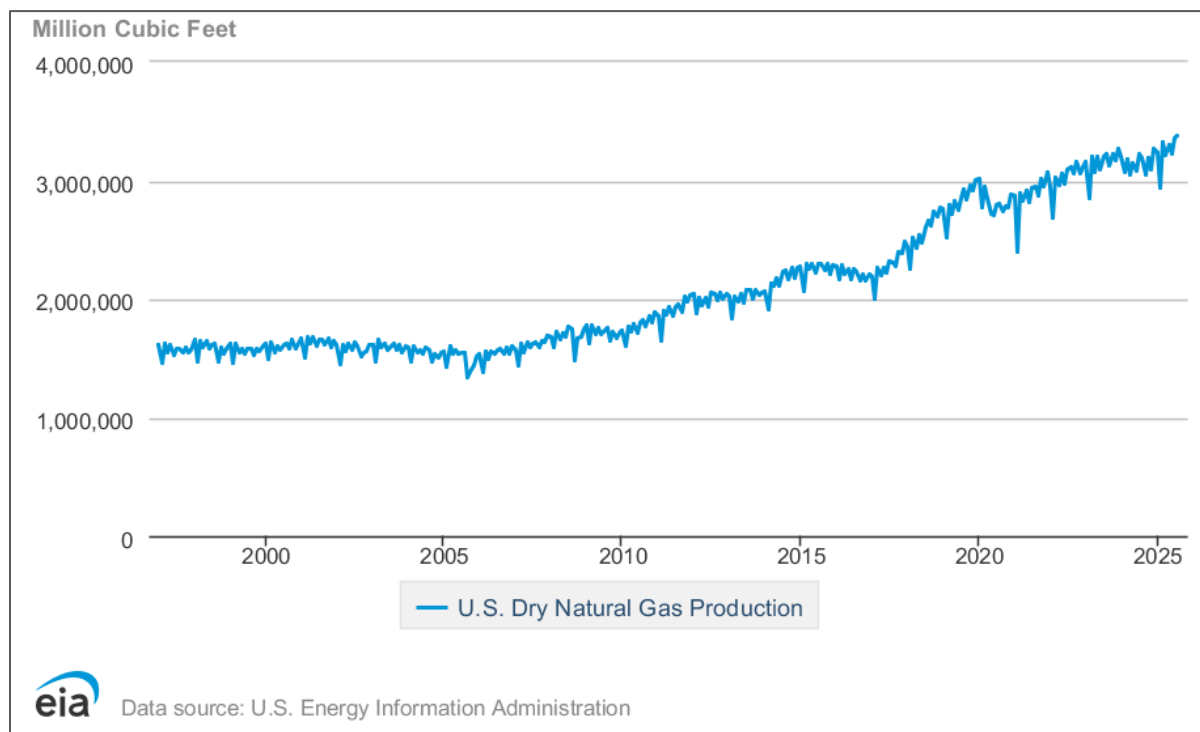


Figure 3.15. Changes in natural gas production 1995 to 2025
<https://www.eia.gov/dnav/ng/hist/n9070us2m.htm>.



Test your knowledge...

- 1) *What is the chemical formula for natural gas?*
- 2) *Natural gas can be compressed into _____ for easy transportation*
- 3) *Natural gas is often found in association with _____ deposits*
- 4) *_____ is a method of extracting natural gas from shale rock*

3.6 Fossil Fuels and Greenhouse Gases

Fossil fuels are made up mainly of hydrogen and carbon. When burned, the carbon combines with oxygen to create carbon dioxide (CO₂). The amount of CO₂ produced depends on the carbon content of the fuel. For example, for the same amount of energy produced, natural gas produces about half and petroleum produces about three-fourths of the amount of CO₂ produced by coal. Energy-related CO₂ emissions, resulting from the combustion of coal, petroleum, and natural gas, account for about 80% of total U.S. human-caused (anthropogenic) greenhouse gas (GHG) emissions. There are many sources of non-energy CO₂ emissions, but those emissions account for a relatively small share of total GHG emissions. See chapter 6 for a discussion of the results of GHG emissions.

Energy use continues to be influenced by economic growth and weather patterns that affect heating and cooling needs. The mix of fuels used for electricity generation significantly impacts greenhouse gas (GHG) emissions. In the United States, natural gas is now the largest source of electricity, followed by renewables, nuclear, and coal. Coal's share has declined substantially, and while it remains the most carbon-intensive fuel, natural gas now accounts for a greater share of total emissions from electricity generation because of its dominant role in power production. Although the industrial sector remains the largest consumer of total energy (including direct fuel use and purchased electricity), the transportation sector continues to emit the most carbon dioxide due to its near-complete reliance on petroleum fuels (**Figure 3.16**). The residential and commercial sectors have lower emissions, most of which result from fossil fuel combustion for electricity generation.

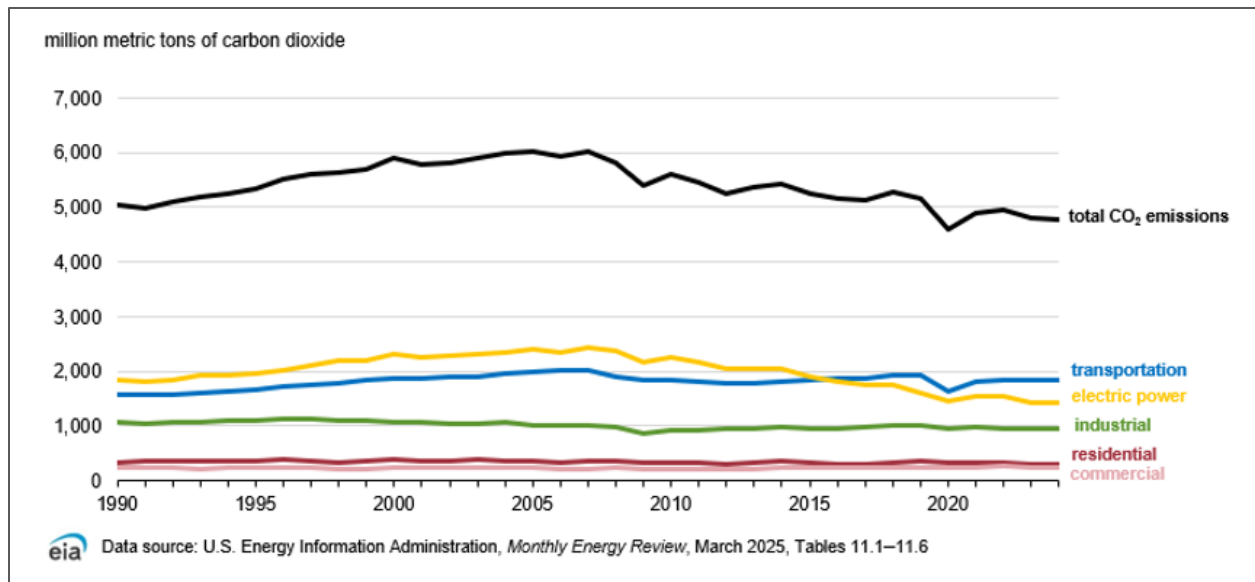


Figure 3.16: Shows that electric power sector emissions have declined significantly since 2005, largely due to the shift from coal to natural gas and the growth of renewables, while transportation emissions remain the highest among all sectors Based on data from U.S. Energy Information Administration Source: [EIA](https://www.eia.gov)



Test your knowledge...

1. T/F: Natural gas emits more carbon dioxide per unit of energy than coal
2. T/F: Fossil fuel combustion is the primary source of greenhouse gas emissions in the U.S.
3. T/F: The transportation sector emits more carbon dioxide than electricity generation in the U.S.

3.7 Nuclear Energy

Nuclear energy is energy in the **nucleus** (core) of an atom (see chapter 1 for a review of atomic structure). There is enormous energy in the forces that hold protons and neutrons in the nucleus together. Energy is released when those forces are broken. Nuclear energy can be released from atoms by splitting apart the nucleus of an atom to form smaller atoms, a process known as **nuclear fission**. During nuclear fission, a small atomic particle called a **neutron** hits the uranium atom and splits it, releasing a great amount of energy in the form of heat and **radiation**. More neutrons are also released when the uranium atom splits. These neutrons go on to bombard other uranium atoms, and the

process repeats itself over and over again. This is called a **chain reaction** (Figure 3.17). Nuclear power plants use the energy from nuclear fission to produce electricity.

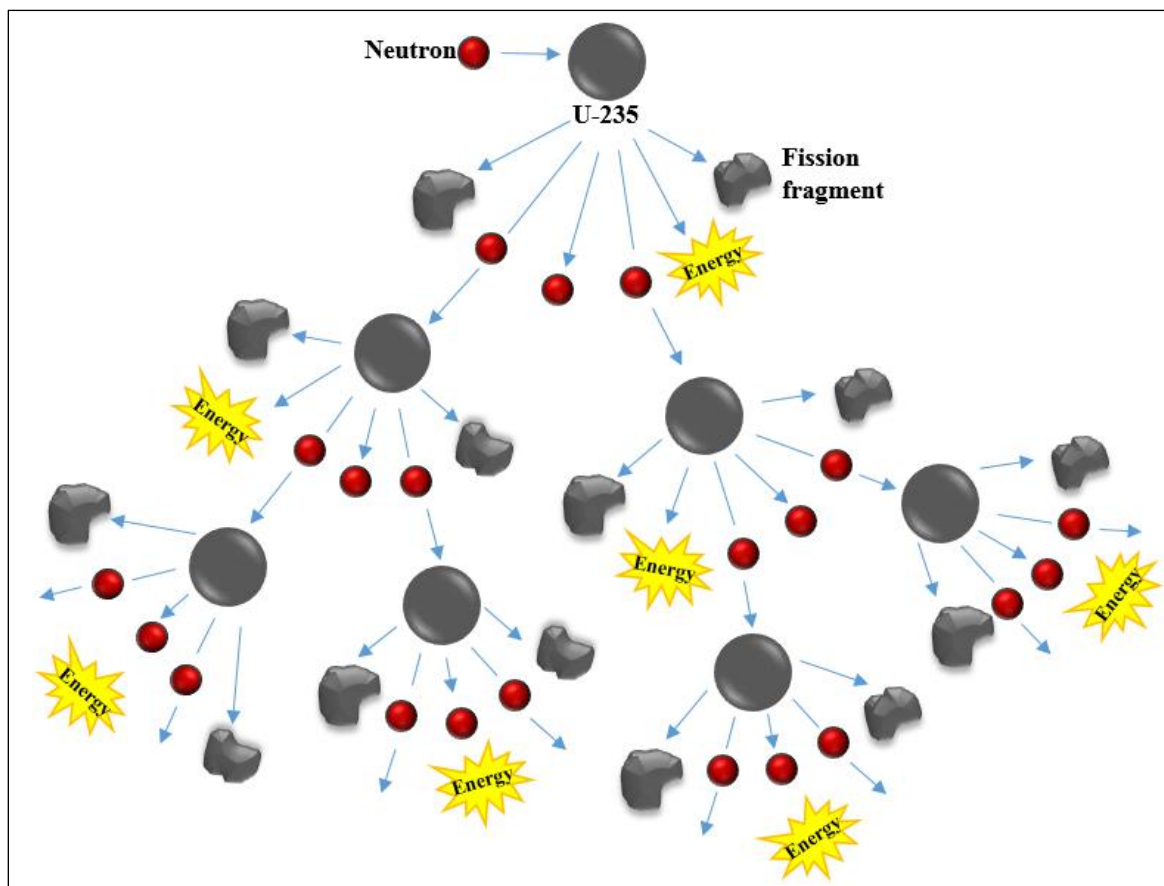


Figure 3.17: Fission chain reaction – begins when a neutron bombards a U-235 atom, splitting it into two fission fragments, along with more neutrons and energy. The neutrons bombard other uranium atoms releasing more energy and more neutrons and the reaction continues.

3.7.1 Nuclear Fuel Processing

Uranium is a naturally occurring radioactive element that decays into daughter **isotopes** (see chapter 1 for a review of isotopes), releasing radiation energy in the process. There are three naturally occurring isotopes of uranium almost all (99.27 %) of which is uranium-238 (U-238); the remainder consists of U-235 (0.72 %) and U-234 (0.006 %). **U-235** is the preferred nuclear fuel because when its atoms are split (fissioned), they not only emit heat and high energy radiation but also enough neutrons to maintain a chain reaction and provide energy to power a nuclear power plant. Uranium is found in rocks all over the world but is relatively rare and the supply is finite making it a nonrenewable energy source.

Uranium usually occurs in combination with small amounts of other elements and once it is mined, the U-235 must be extracted and processed before it can be used as a fuel in a nuclear power plant to generate electricity. The process begins with **exploration** for uranium and the development of mines to extract the discovered **ore** (*ore* refers to rock

that contains minerals of economic importance). Mining is either conventional (underground or open pit) or unconventional, such as in-place solution mining or heap leaching, which use liquid solvents to dissolve and extract the ore. Mined uranium ore (**Figure 3.18 A**) typically yields one to four pounds of uranium concentrate per ton of uranium ore (0.05% to 0.20%).

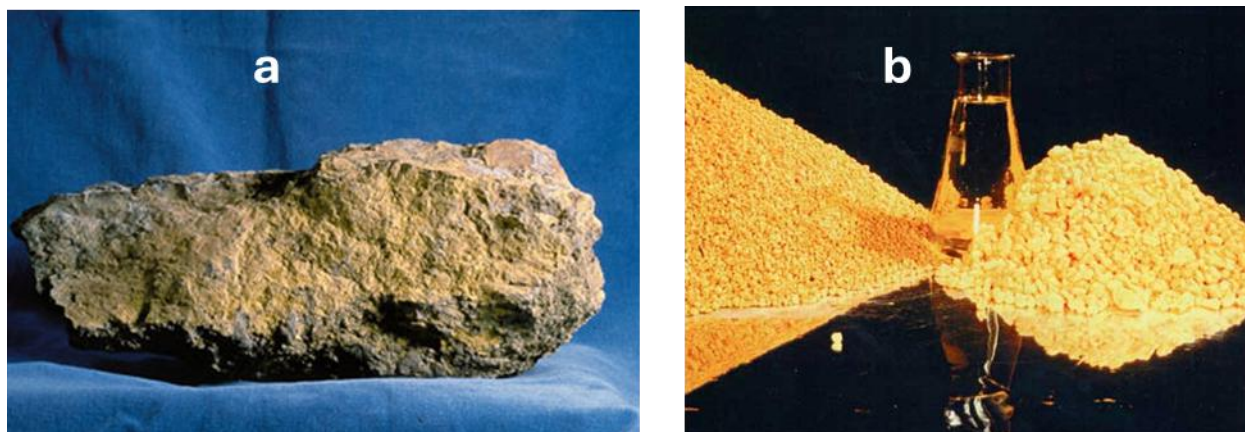


Figure 3.18: A) Uranium ore B) Yellowcake (U_3O_8). Images obtained from United States Geological Survey (A) and United States Department of Energy (B).

Uranium ore from a conventional mine is usually refined into uranium concentrate in a process referred to as **milling**. The ore is crushed and ground into fine powder that is then reacted with chemicals to separate the uranium from other minerals. The concentrated uranium product is typically a bright yellow or orange powder called *yellowcake* (U_3O_8) (**Figure 3.18 B**), and the waste stream from these operations is called *mill tailings*. Uranium ore in solution is also milled into yellowcake by retrieving the uranium out of the solution and concentrating it.

The yellowcake then undergoes **conversion** into uranium hexafluoride (UF_6) gas. This step enables the atomic segregation of the three naturally occurring uranium isotopes in to individual components. In the UF_6 gas, the original concentrations of uranium isotopes are still unchanged. This gas is then sent to an **enrichment** plant where the isotope separation takes place and the concentration of U-235 is increased to about a 4% to 5% (compared to 0.72 % original concentration). The product, called *enriched* UF_6 , is sealed in canisters and allowed to cool and solidify before it is transported to a fuel assembly plant.

The next step in the production of nuclear fuel takes place at fuel **fabrication** facilities. Here, the enriched UF_6 gas is reacted to form a black uranium dioxide (UO_2) powder. The powder is then compressed and formed into the shape of small ceramic *fuel pellets* (**Figure 3.19 A**). Each ceramic pellet produces roughly the same amount of energy as 150 gallons of oil. The pellets are stacked and sealed into long metal tubes that are about 1 centimeter in diameter to form **fuel rods**. (**Figure 3.19 B**) fuel rods are then bundled together to make up a *fuel assembly* (**Figure 3.19 C**). Depending on the reactor type, there are about 179 to 264 fuel rods in each fuel assembly. A typical reactor core holds 121 to 193 fuel assemblies.

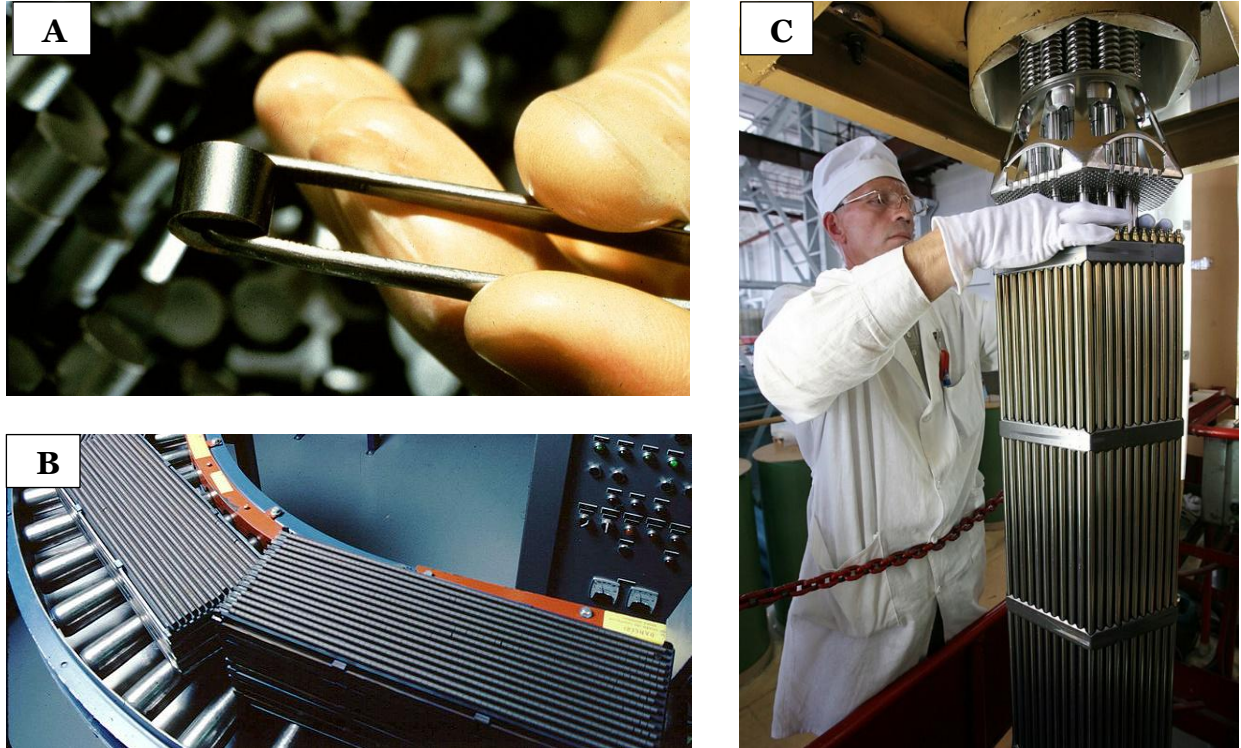


Figure 3.19: Fuel fabrication process. A) Uranium dioxide powder compressed into *fuel pellets*. B) Fuel pellets stacked and sealed in metal tubes forming *fuel rods*. C) Fuel rods are bundled into a *fuel assembly*. Images A and B from NRC (public domain); C from RIA Novosti archive, image #132602 / Ruslan Krivobok / CC-BY-SA 3.0

3.7.2 Nuclear Power Plant

After fabrication, fuel assemblies are transported to nuclear power plants where they are used as a source of energy for generating electricity. They are stored onsite until they are needed by the reactor operators. At this stage, the uranium is only mildly radioactive, and essentially all radiation is contained within the metal tubes. When needed, the fuel is loaded into a reactor core (**Figure 3.20**). Typically, about one third of the reactor core (40 to 90 fuel assemblies) is changed out every 12 to 24 months.

The most common type of reactors are the pressurized water reactors (PWR) (**Figure 3.20**) in which water is pumped through the *reactor core* and heated by the fission process. The water is kept under high pressure inside the reactor so it does not boil. The heated water from the reactor passes through tubes inside the *steam generator* where the heat is transferred to water flowing around the tubes in the steam generator. The water in the steam generator boils and turns to steam. The steam is piped to the turbines. The force of the expanding steam drives the turbines, which spin a magnet in coil of wire – the generator – to produce electricity.

After passing through the turbines, the steam is converted back to water by circulating it around tubes carrying cooling water in the *condenser*. The condensed steam – now water – is returned to the steam generators to repeat the cycle.

The three water systems (condenser, steam generator, and reactor) are separate from each other and are not permitted to mix. Water in the reactor is radioactive and is contained within the containment structure whereas water in the steam generator and condenser is nonradioactive.

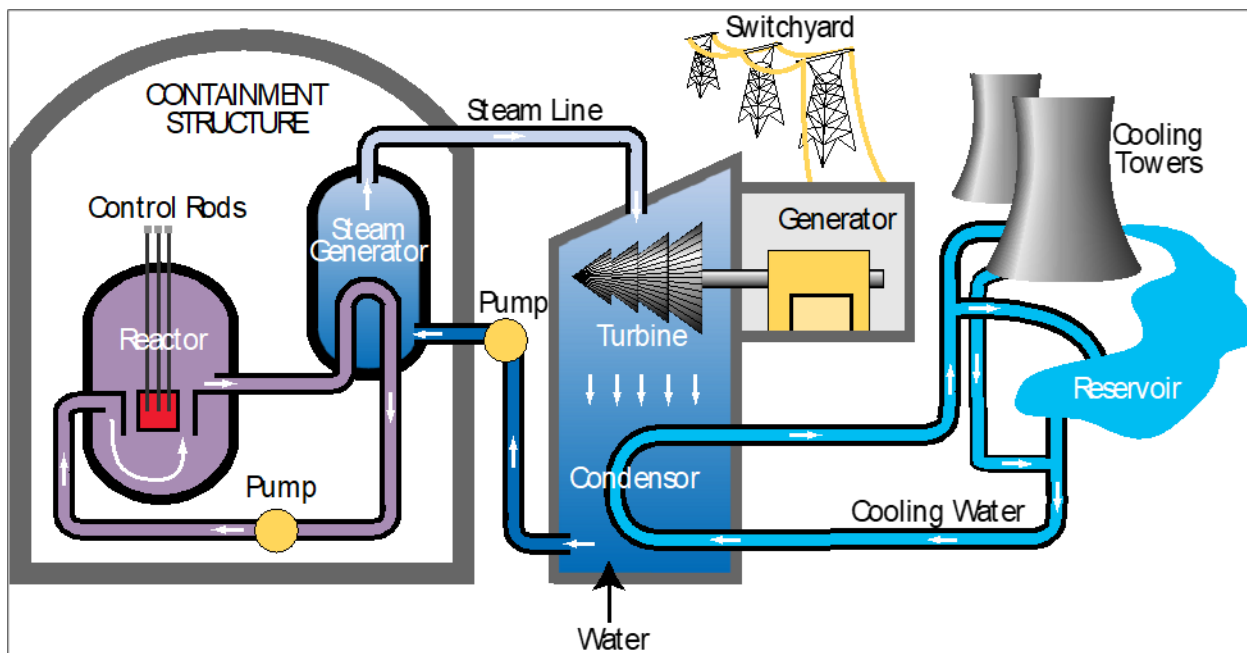


Figure 3.20: A schematic diagram of a pressurized water reactor (PWR), the most common type of nuclear reactor. Diagram from Tennessee Valley Authority (public domain). www.tva.com

3.7.3 Benefits of Nuclear Energy

By using fission, nuclear power plants generate electricity without emitting air pollutants like those emitted by fossil fuel-fired power plants. This means that financial costs related to chronic health problems caused by air pollutants such as particulate material, carbon monoxide, nitrogen oxides and ozone among others are significantly reduced. In addition, nuclear reactors do not produce carbon dioxide while operating which means that nuclear energy does not contribute to the global warming problem.

Another benefit of nuclear energy over fossil fuels especially coal is that uranium generates far more power per unit weight or volume. This means that less of it needs to be mined and consequently the damage to the landscapes is less especially when compared to the damage that results from coal mining such as mountaintop removal.

3.7.4 The Drawbacks of Nuclear Energy

The main environmental concern related to nuclear power is the creation of radioactive wastes such as uranium mill **tailings**, spent (used) reactor fuel, and other radioactive wastes. These materials can remain radioactive and dangerous to human health for thousands of years. Radioactive wastes are classified as low-level and high-level. By volume, most of the waste related to the nuclear power industry has a relatively low-level of radioactivity. Uranium mill tailings contain the radioactive element radium, which decays to produce **radon**, a radioactive gas. Most uranium mill tailings are placed near the processing facility or mill where they come from. Uranium mill tailings are covered with a barrier of material such as clay to prevent radon from escaping into the atmosphere, and they are then covered by a layer of soil, rocks, or other materials to prevent erosion of the sealing barrier.

The other types of low-level radioactive waste are the tools, protective clothing, wiping cloths, and other disposable items that get contaminated with small amounts of radioactive dust or particles at nuclear fuel processing facilities and power plants. These materials are subject to special regulations that govern their handling, storage, and disposal so they will not come in contact with the outside environment.

High-level radioactive waste consists of spent nuclear reactor fuel (i.e., fuel that is no longer useful for producing electricity). The spent reactor fuel is in a solid form consisting of small fuel pellets in long metal tubes called rods. Spent reactor fuel assemblies are initially stored in specially designed pools of water, where the water cools the fuel and acts as a radiation shield. Spent reactor fuel assemblies can also be stored in specially designed dry storage containers. An increasing number of reactor operators now store their older spent fuel in dry storage facilities using special outdoor concrete or steel containers with air cooling. There is currently no permanent disposal facility in the United States for high-level nuclear waste.

When a nuclear reactor stops operating, it must be **decommissioned**. This involves safely removing the reactor and all equipment that has become radioactive from service and reducing radioactivity to a level that permits other uses of the property. The U.S. Nuclear Regulatory Commission has strict rules governing nuclear power plant decommissioning that involve cleanup of radioactively contaminated plant systems and structures, and removal of the radioactive fuel.

A **nuclear meltdown**, or uncontrolled nuclear reaction in a nuclear reactor, can potentially result in widespread contamination of air and water. Some serious nuclear and radiation accidents have occurred worldwide. The most severe accident was the Chernobyl accident of 1986 in the then Soviet Union (now Ukraine) which killed 31 people directly and sickened or caused cancer in thousands more. The Fukushima Daiichi nuclear disaster (2011) in Japan was caused by a 9.0 magnitude earthquake that shut down power supply and a tsunami that flooded the plant's emergency power supply. This resulted in the release of radioactivity although it did not directly result in any deaths at the time of the disaster. Another nuclear accident was the Three Mile Island accident (1979) in Pennsylvania, USA. This accident resulted in a near disastrous core meltdown that was due to a combination of human error and mechanical failure but did not result in any deaths and no cancers or otherwise have been found in follow up studies of this accident. While there are potentially devastating consequences to a nuclear meltdown, the likelihood of one occurring is

extremely small. After every meltdown, including the 2011 Fukushima Daiichi disaster, new international regulations were put in place to prevent such an event from occurring again.

The processes for mining and refining uranium ore and making reactor fuel require large amounts of energy. Nuclear power plants have large amounts of metal and concrete, which also require large amounts of energy to manufacture. If fossil fuels are used for mining and refining uranium ore or in constructing the nuclear plant, then the emissions from burning those fuels could be associated with the electricity that nuclear power plants generate.



Test your knowledge...

Test Your Knowledge

- 1) What is the primary fuel used in nuclear power plants?
a) Coal b) Uranium c) Thorium d) Natural gas
- 2) Which process generates heat energy in a nuclear power plant?
a) Combustion b) Nuclear fusion c) Nuclear fission d) Bombardment
- 3) T/F Nuclear power plants emit large amounts of carbon dioxide during electricity generation
- 4) The main challenge of nuclear energy is the safe disposal of _____
- 5) _____ refers to the process of increasing the proportion of uranium 235

3.8 Looking Ahead

Although non-renewable energy sources such as coal, oil, and natural gas continue to supply most of the world's energy, global demand patterns are showing promise. For example, in 2024, growth in fossil fuel use was comparatively modest, reflecting improved energy efficiency, economic shifts, and expanding climate policies across many countries. In contrast, renewable energy experienced the fastest rate of demand growth of all major energy sources (**Figure 3.21**), driven by declining technology costs, new policy incentives, and record additions of solar and wind capacity.

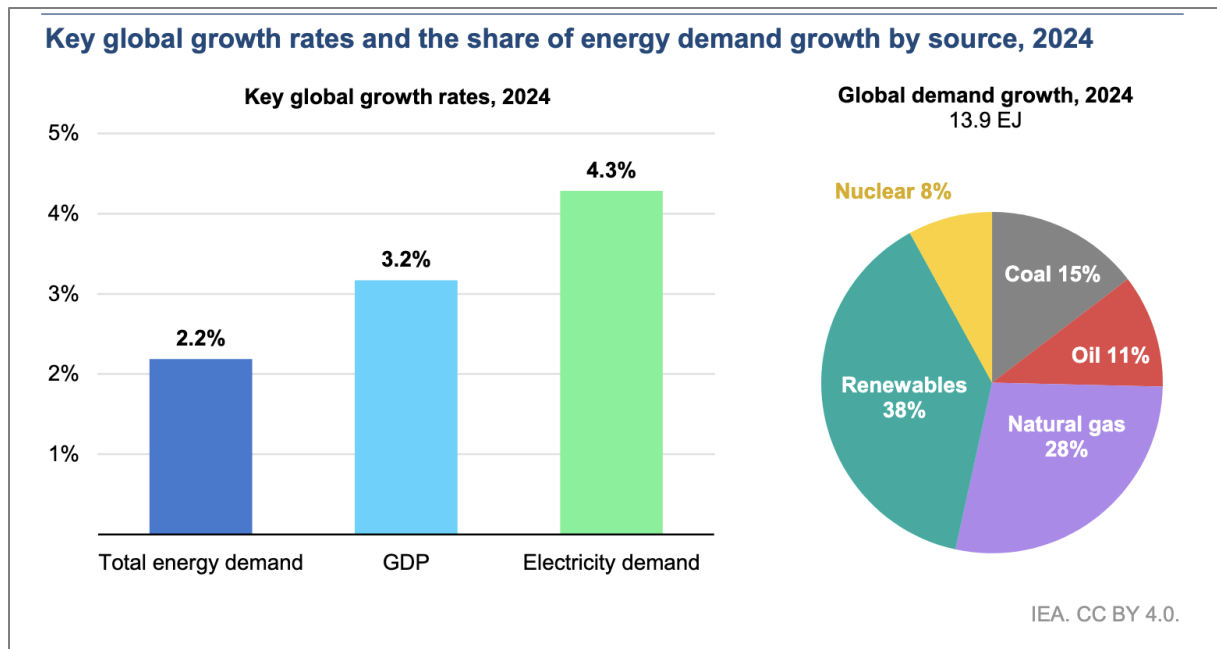


Figure 3.21. Growth in energy demands for 2024 shows the continuing growth in energy needs. Growth in demand for electricity was greater than growth in total energy demand and renewables had the largest growth (Source: [IEA](#)).

This recent trend marks an important turning point. Even though fossil fuels remain dominant in total global energy consumption, renewables are now leading the expansion of new energy supply. As the world adds more generating capacity, a growing share is coming from clean energy technologies rather than conventional non-renewable sources. The momentum behind renewables is reshaping energy systems worldwide and creating new opportunities for electricity generation, storage, and grid modernization. The next chapter explores these renewable energy resources in detail including what they are, how they work, and how they are transforming the global energy landscape.

End of Chapter Review

1. Define *energy* in your own words and explain why it is essential for all human activities.
2. Describe the difference between potential and kinetic energy and give one example of each.
3. Explain why understanding different forms of energy is important for evaluating energy resources.
4. What are fossil fuels, and how did they form?
5. Compare the formation processes of coal, oil, and natural gas. What conditions influence which fuel forms?

6. Describe global patterns in fossil fuel consumption. Which regions use the most, and why?
7. Explain how coal is mined and processed prior to electricity generation.
8. How do we go from coal to electricity?
9. List three major environmental impacts of coal mining and combustion.
10. What is oil refining, and why is it necessary?
11. Identify two major environmental impacts of oil extraction or use.
12. Explain how hydraulic fracturing (“fracking”) works and summarize one benefit and one drawback of this method.
13. Which fossil fuel releases the most CO₂ per unit of energy produced? Which releases the least? Why?
14. What is nuclear fission, and how does it produce energy?
15. List two major benefits of nuclear energy and two major drawbacks.
16. Why is the management of nuclear waste such a challenge?
17. If you were advising a government planning for future energy needs, what mix of energy sources would you recommend and why?
18. What is the primary environmental concern associated with coal combustion?
 - a. Methane leakage
 - b. High CO₂ emissions and sulfur dioxide
 - c. Radioactive waste
 - d. Oil spills
19. Which product is NOT typically derived from crude oil refining?
 - a. Gasoline
 - b. Diesel
 - c. Natural gas
 - d. Jet fuel
20. Which extraction method is commonly used for shale gas?
 - a. Offshore drilling
 - b. Strip mining
 - c. Hydraulic fracturing
 - d. Gasification
21. Crude oil primarily originated from:
 - a. Swamp plants
 - b. Volcanic ash
 - c. Marine organisms
 - d. Desert vegetation
22. What is the main component of natural gas?
 - a. Ethane
 - b. Methane
 - c. Propane
 - d. Butane
23. Which extraction method is commonly used for shale gas?
 - a. Offshore drilling
 - b. Strip mining
 - c. Hydraulic fracturing
 - d. Gasification

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Terms

Acid mine drainage	Hydraulic fracturing
Anaerobic	Hydrocarbon
Ash	Isotope
Bioaccumulation	Kinetic energy
Biodiversity	Liquid natural gas
Biomagnification	Mercury
Boiler	Methane
Butane	Methylmercury
Caprocks	Milling
Carbon capture and sequestration	Mountaintop removal
Carbon dioxide	Natural gas
Carbon monoxide	Neutron
Chain reaction	Nitrogen oxides
Chemical energy	Non-renewable resource
Clean Air Act	Nuclear energy
Clean coal technology	Nuclear fission
Clean Water Act	Nuclear meltdown
Coal	Nucleus
Coal-fire power plant	Offshore drilling
Condenser	Oil
Conversion	Oil spill
Crude oil	Onshore drilling
Decommissioned	Ore
Digester	Overburden
Dry natural gas	Particulate matter
Electricity	Petroleum
Energy	Pipeline
Enrichment	Plastics
Exploration	Potential energy
Fabrication	Primary energy
Fossil fuel	Propane
Fuel rod	Radiation
Furnace	Radon
Generator	Reclamation
Greenhouse gas	Refinery
Heating value	Scrubber
Heavy metals	Secondary energy

Separation
Strip mining
Sulfur dioxide
Tailing
Transportation
Treatment
Turbine
U-235
Underground mining
Uranium
Volatile organic compound
Wet natural gas