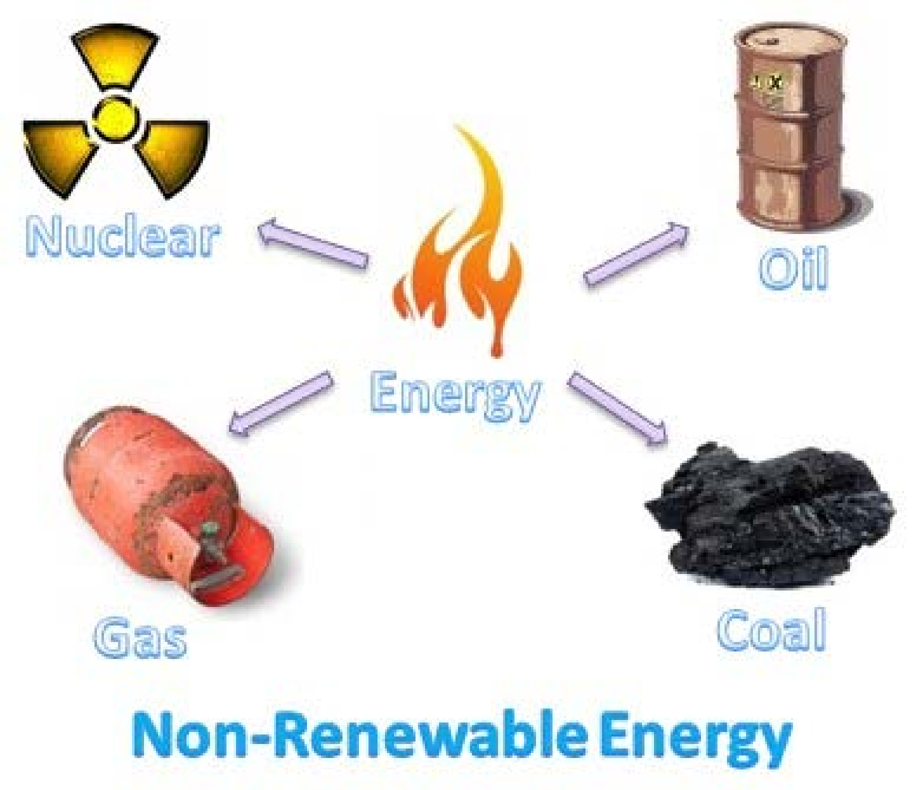
Nonrenewable Energy Resources

Chapter 12



V. Energy Resources and Consumption (10-15%)

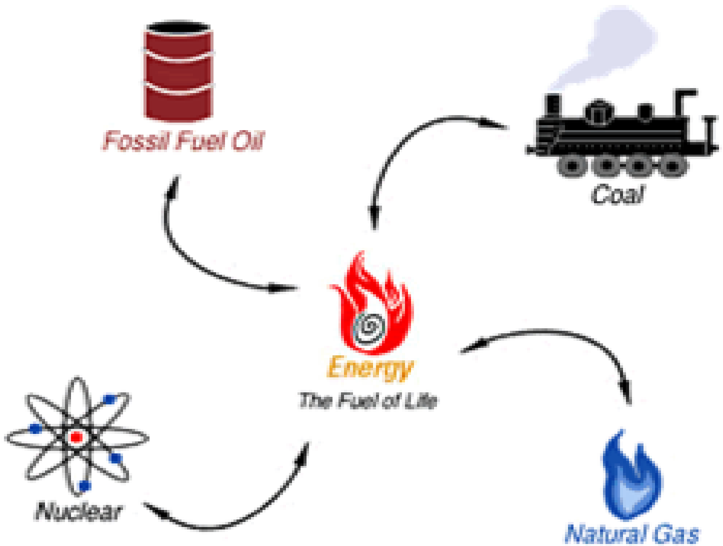
A. Energy Concepts
B. Energy Consumption
C. Fossil Fuel Resources and Use
D. Nuclear Energy

Module 34: Patterns of Energy Use

After this module you will be able to……

1) Describe the use of nonrenewable energy in the world and in the United States
2) Explain why different forms of energy are best suited for certain purposes
3) Understand the primary ways that electricity is generated in the United States

Nonrenewable Energy Use Around The World



Fossil fuels are fuels derived from biological material that fossilized millions of years ago. These fuels provide the most energy used in developed and developing countries.

The vast majority of fossil fuels are coal, oil, and natural gas, and come from deposits of organic matter that were formed 50 million to 350 million years ago. Since we can not replenish fossil fuels once they are used up it is known as a **nonrenewable energy source**.

Nonrenewable Energy Use Around The World

Nuclear fuels are derived from radioactive materials that give off energy. Although the supply of these fuels are finite, the current rates of consumption will allow it to last for a very long time.

Worldwide Patterns of Energy Use

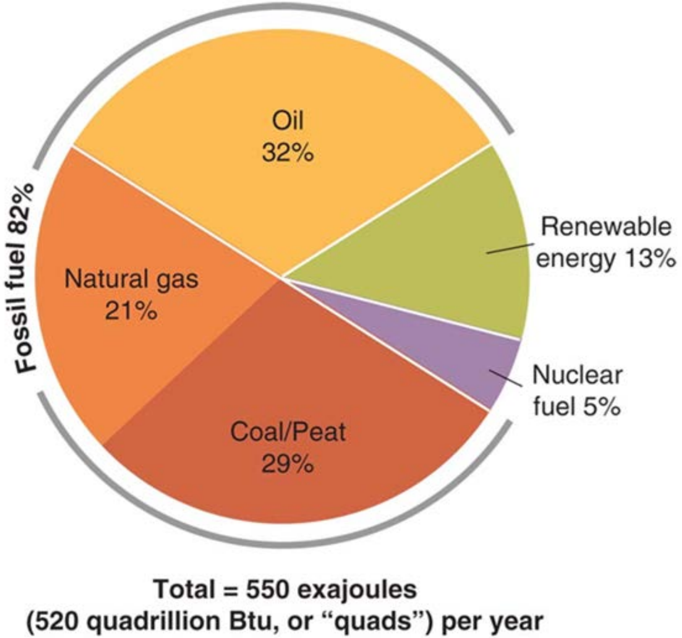


Figure 34.1
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Data from the International Energy Agency, 2013

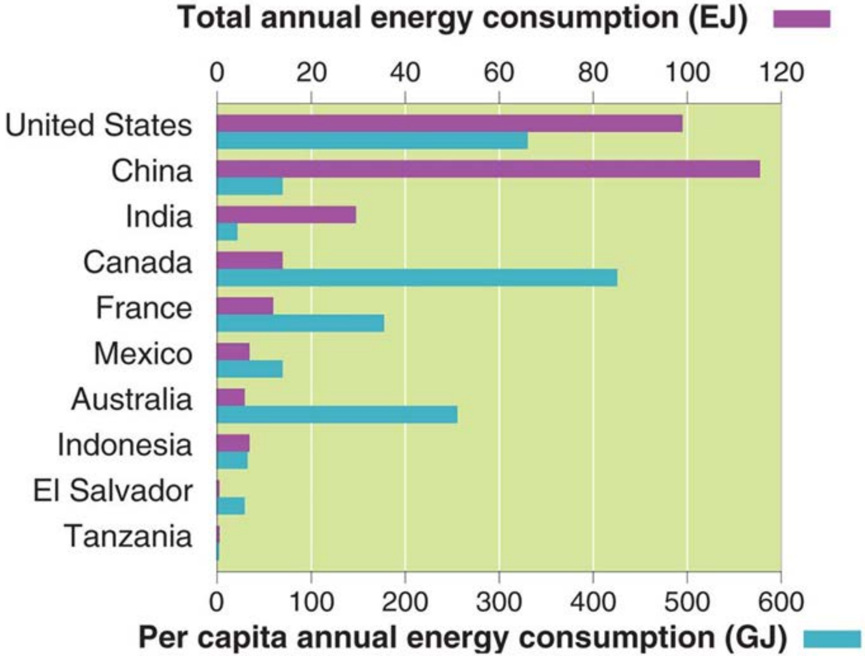

Figure 34.2
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Data from the U.S. Department of Energy, Energy Information Administration, 2012

Worldwide Patterns of Energy Use

Commercial energy sources are those that are bought and sold, such as coal, oil, and natural gas, and sometimes wood, charcoal, and animal waste.

Subsistence energy sources are those gathered by individuals for their own immediate needs and include straw, sticks, and animal dung.

There is much greater use of subsistence energy sources in the developing world. Changes in demand generally reflect the level of industrialization in a country or region. For example, as more people own automobiles the demand for gasoline and diesel fuel increases.

Energy Use in the United States

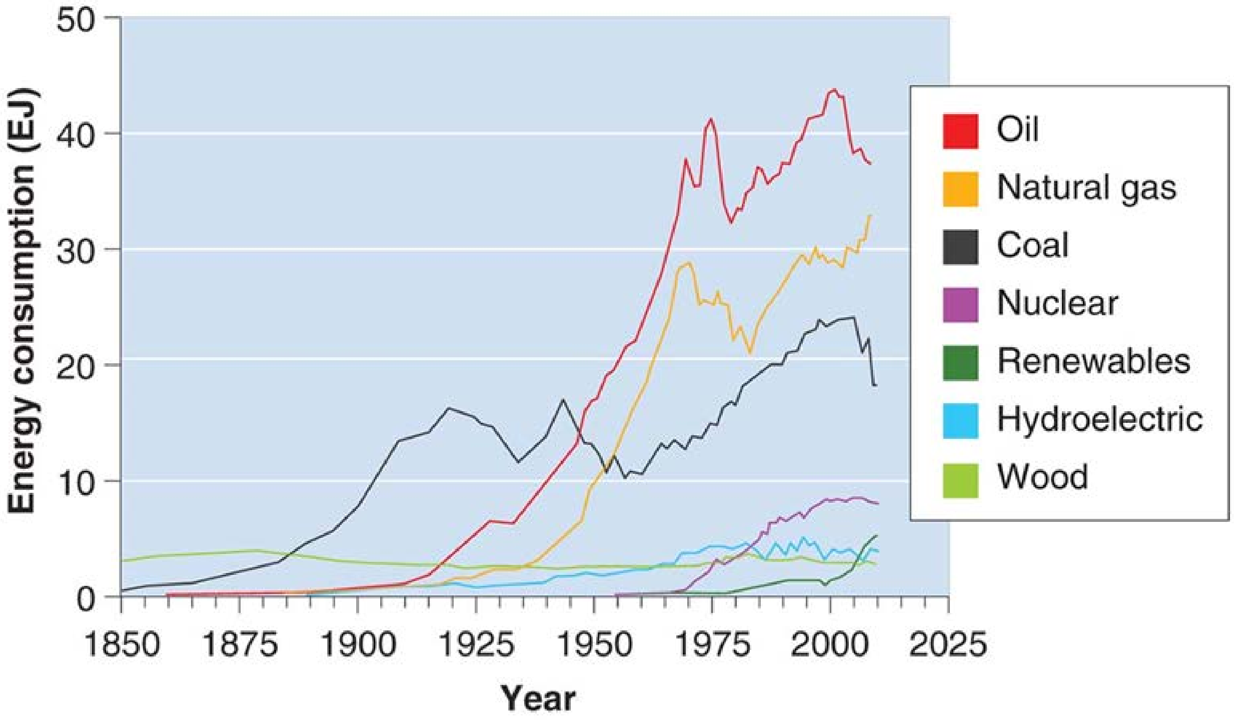

Figure 34.3
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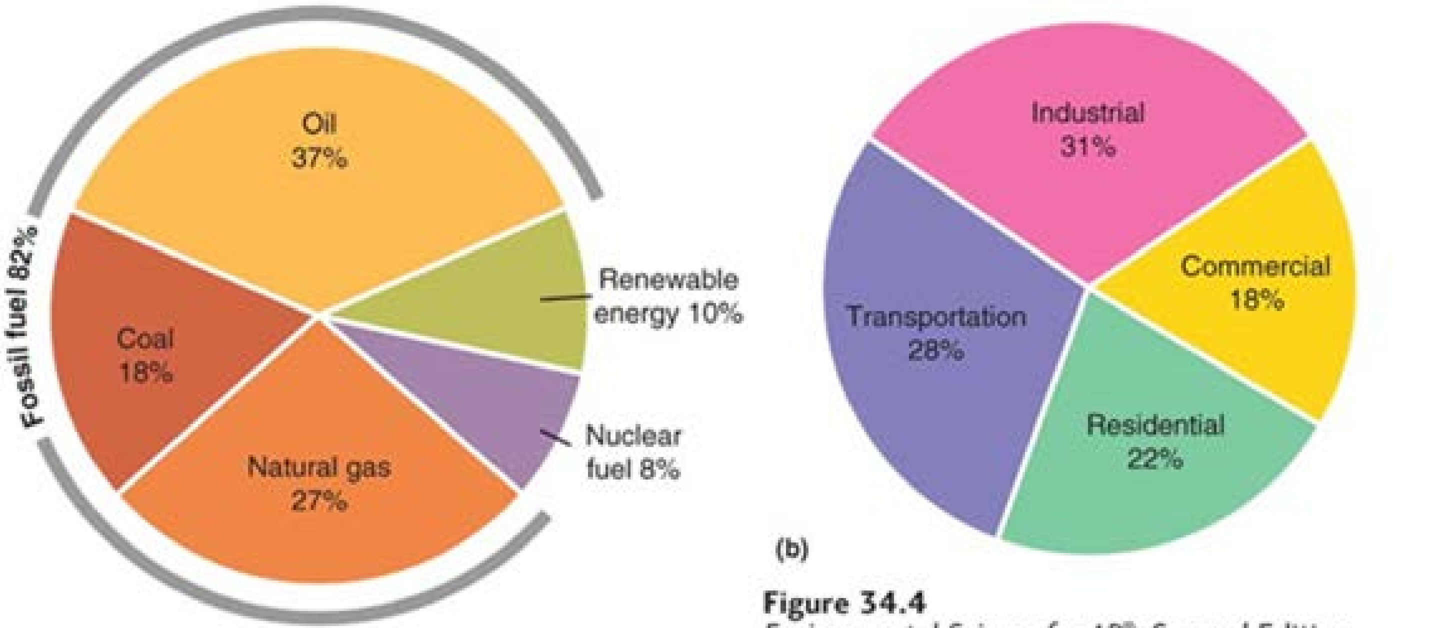
After U.S. Department of Energy, Energy Information Administration, 2013

Energy Use in the United States



(a) Total = 100 exajoules (95 quads) per year

Figure 34.4
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Data from U.S. Department of Energy, Energy Information Administration, 2013

Energy Forms Depend on Purpose

The best form of energy to use depends on the particular purpose. For example, we prefer gasoline or diesel fuel for transportation. This is because liquid energy sources are relatively compact, meaning they have high energy-to-mass ratio. Recently, as energy storage capacity in batteries have improved and their price decreasing, many car companies are using electricity to power their vehicles.

Quantifying Energy Efficiency

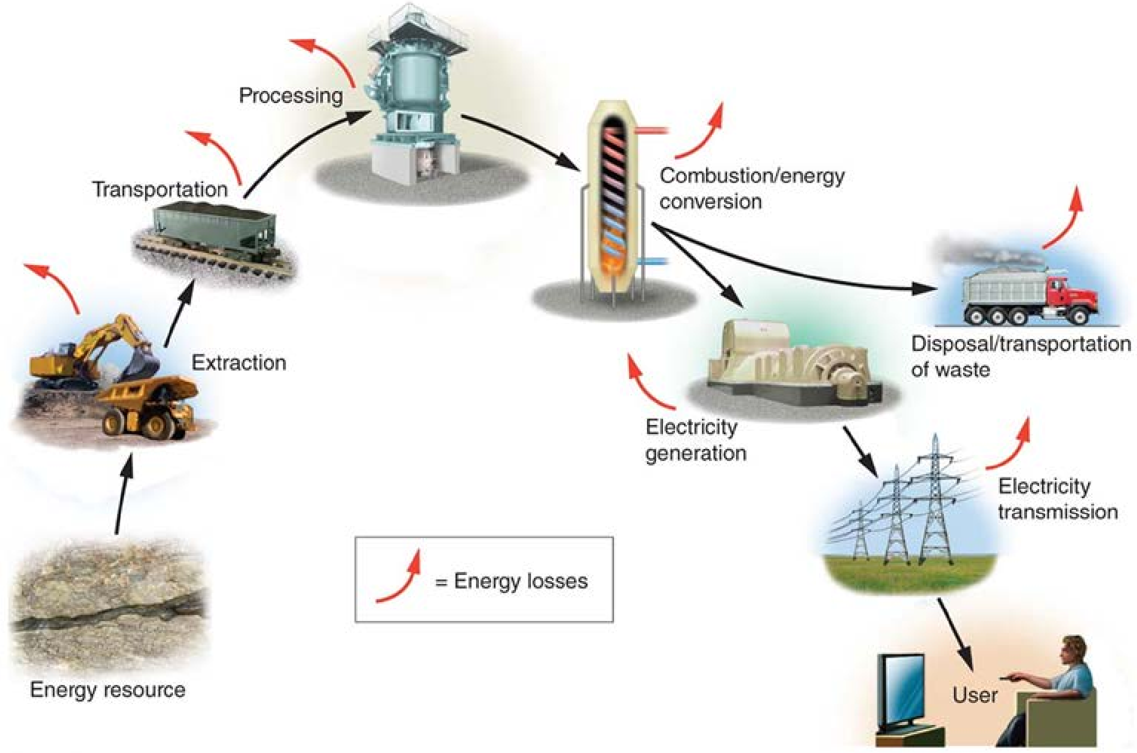

Figure 34.5
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Energy efficiency refers to both the efficiency of the process we use to obtain the fuel and the efficiency of the process that converts the fuel into the work that is needed.

The efficiency of converting coal into electricity is approximately 35 percent.

Quantifying Energy Efficiency

EROEI is the energy return on energy investment. It can be calculated as follows:

$$EROEI = \frac{Energy\ obtained\ from\ the\ fuel}{Energy\ invested\ to\ obtain\ the\ fuel}$$

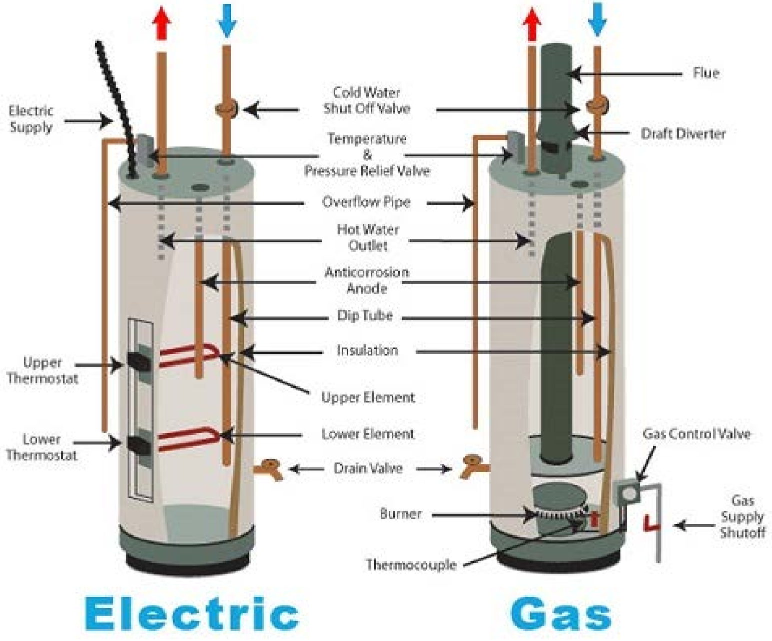
Example: In order to obtain 100 J of coal from a surface coal mine, 5 J of energy is expended. Therefore,

$$100\,J\ EROEI = \frac{100\ J}{5\ J} = 20$$

Finding the Right Energy Source

When deciding between two energy sources for a given job, it’s essential to consider the overall system efficiency.

The electric water heater is often described as being highly efficient compared to natural gas water heaters (99% vs 60%). However, the conversion of fossil fuel into electricity is only about 35% efficient, whereas, the gas water heater is 60% efficient.



Efficiency and Transportation

TABLE 34.1 Energy expended for different modes of transportation in the United States

Mode	MJ per passenger-kilometer
Air	2.1
Passenger car (driver alone)	3.6
Motorcycle	1.1
Train (Amtrak)	1.1
Bus	1.7

Table 34.1
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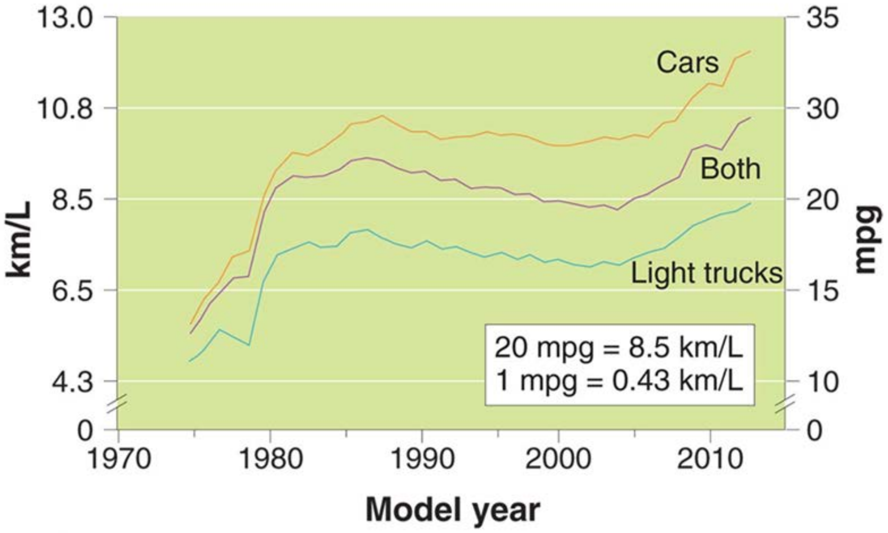

Figure 34.6
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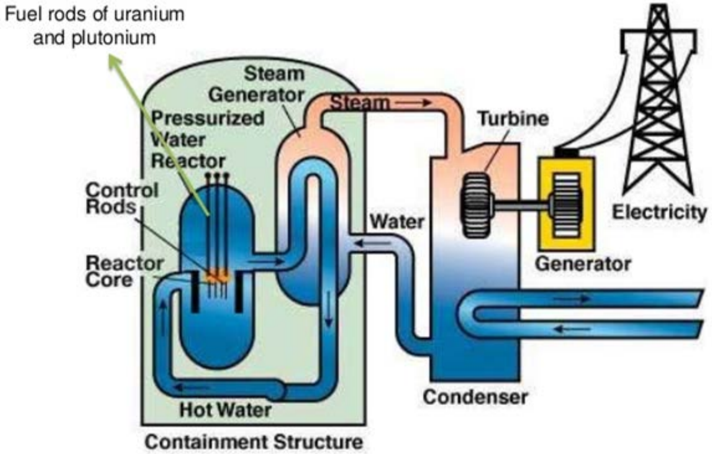
After U.S. Environmental Protection Agency, 2013

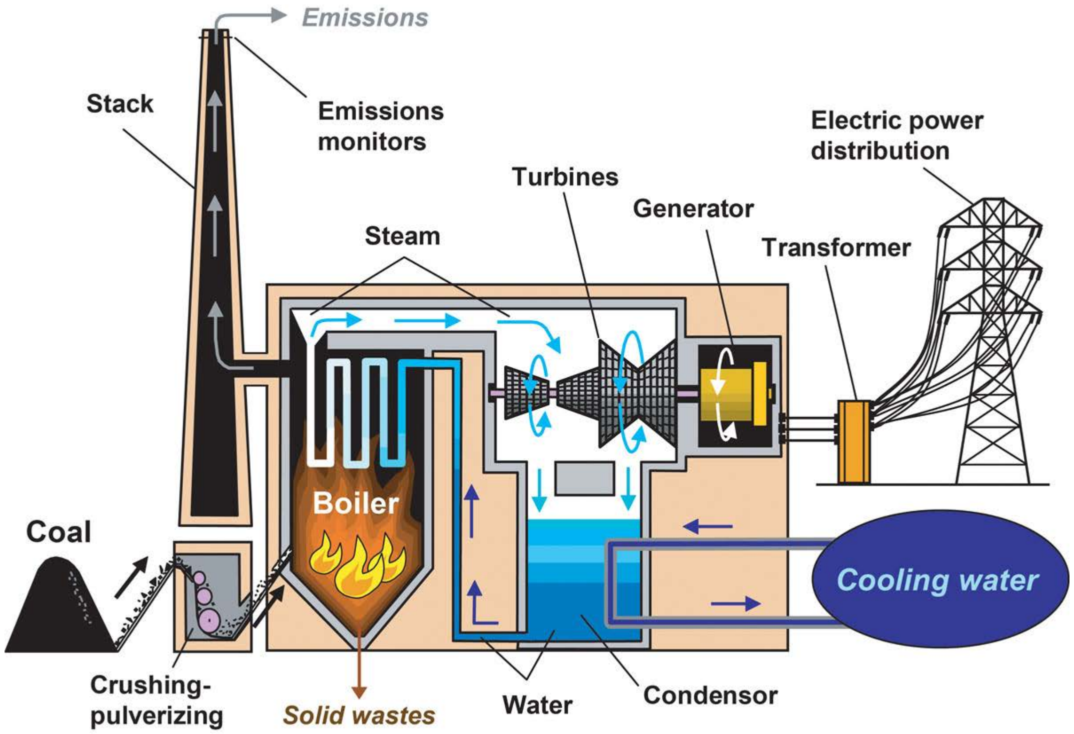
Electricity Energy Use



Electricity accounts for 40 percent of our energy use. It can be generated from many different sources including fossil fuels, wind, water, and the Sun. The primary sources are coal, oil, and natural gas, while the secondary source is electricity. This means we obtain the energy from the conversion of a primary source.

An **energy carrier** is something that can move and deliver energy in a convenient, usable form to end users. Even though 40 percent of our energy consumption is used to generate electricity, only about 13 percent of this energy is available for end users.

Electricity Energy Use



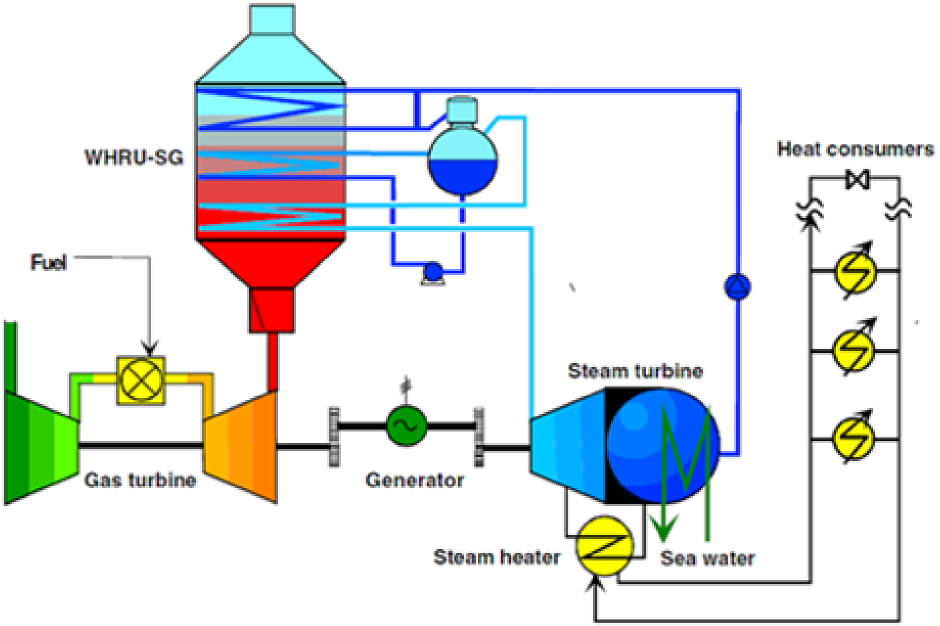
Electricity is produced by converting primary sources, such as coal, natural gas, or wind. Electricity is also clean at the point of use. However, pollutants are released when electricity is produced by combustion of fossil fuels.

Electricity Energy Use

In a coal-burning power plant, fuel is delivered to a boiler and burned. The energy contained within the combusted fuel is transferred to water which becomes steam. The kinetic energy contained within the steam is transferred to the blades of a **turbine**, a device that can be turned by water, steam, or wind to produce power. As the energy turns the turbine, the shaft turns a generator, generating electricity. This electricity is then transported along a network of interconnected transmission lines known as the **electrical grid**, which connects electricity generation sources and links them with the end users of electricity.

Electricity Energy Use

An improvement in gas combustion technology has led to the **combined cycle** natural gas-fired power plant, which uses both exhaust gases and steam turbines to generate electricity. The natural gas is combusted using a gas turbine and the waste heat produced boils water which turns a steam turbine. This raises the efficiency from ~35 percent to ~60 percent.



Electricity Energy Use

The **capacity** of a power plant is its maximum electrical output. A typical power plant in the United States may have a capacity of 500 megawatts (MW).

Recall:
1 W = 1 J/s

So a 500 MW power plant equals 12,000 megawatt-hours. Most home electricity is measured in kilowatt-hours. So...

12,000 MWh x 1,000 kWh/MWh = 12,000,000 kWh in a day.

Most power plants do not operate every day of the year. The fraction of time a power plant operates in a year is known as the **capacity factor**.

Electricity Energy Use

The use of a fuel to generate electricity and produce steam heat is known as **cogeneration**, also called **combined heat and power**. This allows for efficiencies up to 90 percent, whereas, steam heating alone might only be 75 percent efficient and electricity generation might only be 35 percent efficient.

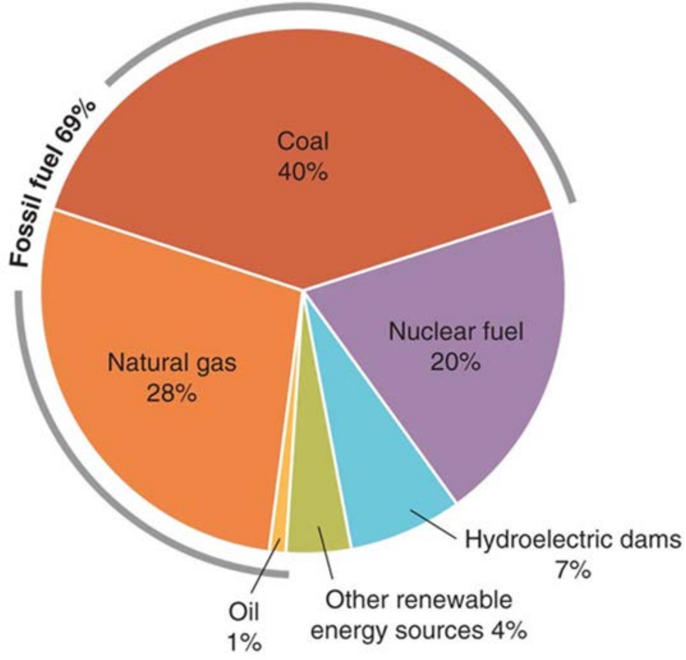


Figure 34.8
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Data from U.S. Department of Energy, Energy Information Administration, 2013

Module 35: Fossil Fuel Resources

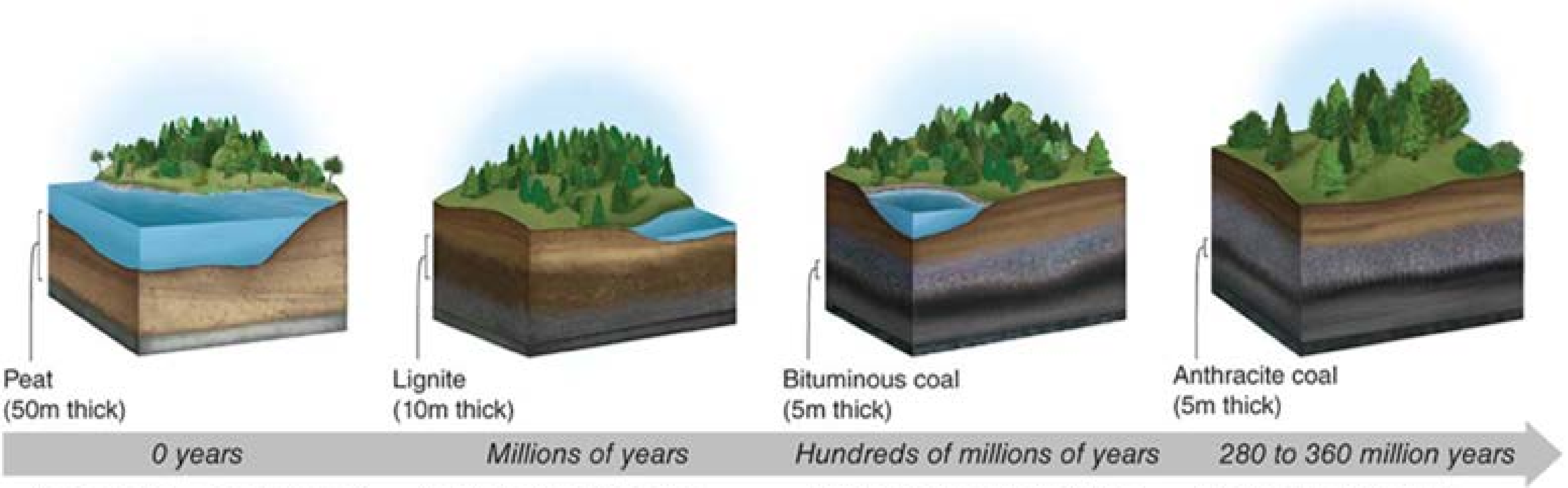
After this module you will be able to……

1) Discuss the uses of coal and its consequences
2) Discuss the uses of petroleum and its consequences
3) Discuss the uses of natural gas and its consequences
4) Discuss the uses of oil sands and liquefied coal and their consequences
5) Describe future prospects for fossil fuel use

Coal is a solid fuel formed primarily from the remains of trees, ferns, and other plant materials that were preserved 280 million to 360 million years ago.

The largest coal reserves are found in the United States, Russia, China, Australia, and India.

A precursor to coal, called peat, is made up of partly decomposed organic material, including mosses. It is compressed over time creating more potential energy, per kilogram.



Ancient forests cover much of land surface. The vegetation dies and is buried under anaerobic conditions, forming peat (partially decomposed organic matter).

As layers of peat become buried deeper below the surface of Earth, they are compressed into lignite.

Lignite layers are buried even deeper. The increased pressure compresses lignite into soft, bituminous coal.

Deeper burial, years of increased pressure, tectonic activity, and heat transform bituminous coal into harder anthracite coal.

Figure 35.1
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Coal Advantages

Coal is energy-dense and plentiful. It’s relatively easy to exploit coal reserves by surface mining in many parts of the world. The technological demands for surface mining are relatively low and it has low economic costs. It’s also relatively easy to handle once extracted and needs little refining. It’s also very easy to transport coal by train, barge, or truck.

Coal Disadvantages

Eventually, we have to resort to subsurface mining when coal becomes harder to find. Coal also contains impurities such as sulfur that is released into the air when burned. There are also trace metals such as lead and arsenic.

Some companies wash their coal to clean these elements. In 2014 a leak occurred in West Virginia polluting the water. The residual ash from coal combustion can also pose a problem. In 2008, a power plant in Knoxville, Tennessee had a containment of this ash that gave way and spilled 4.1 billion liters of ash destroying multiple houses and covered over 300 acres of land. It took 5 years and over $1 billion to clean up the bulk of the ash.

Finally, coal produces a large amount of CO_2, thus increasing the atmospheric concentrations of CO_2.

Coal

Advantages

- Energy-dense
- Easy to exploit
- Small technological demands
- Low economic costs for surface mining
- Easy to handle after extraction
- Easy to transport

Disadvantages

- Subsurface mining becomes necessary which increases cost and technological demands
- Contains impurities (heavy sulfur)
- Contains trace metals (Hg, Pb, As)
- Residual coal ash
- Can pollute water from cleaning
- Releases a large amount of CO_2

Coal Disadvantages

Petroleum

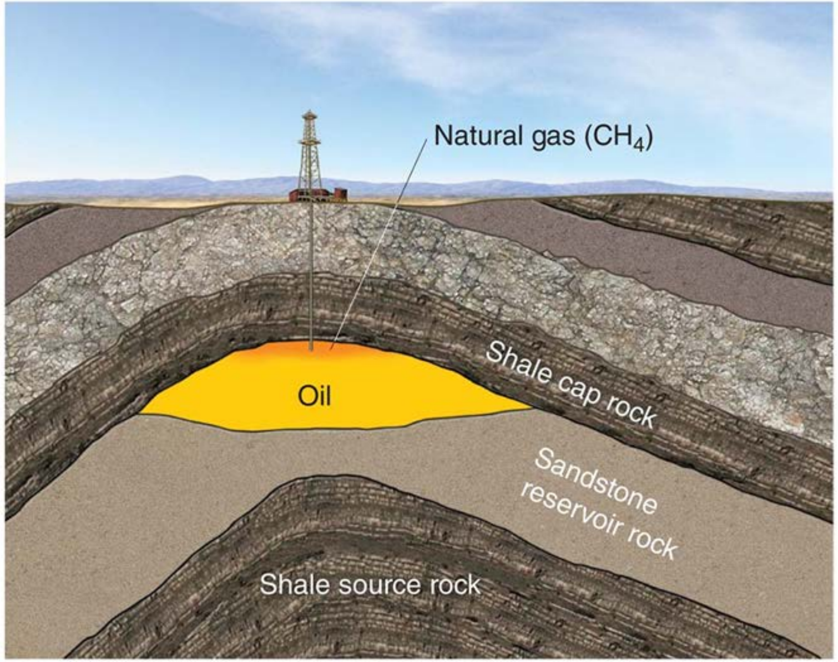

Figure 35.3
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Petroleum, another widely used fossil fuel, is a liquid mixture of hydrocarbons, water, and sulfur that occurs in underground deposits. Liquid petroleum that is removed from the ground is **crude oil**. Petroleum is the preferred method for mobile combustion.

Petroleum is formed from the remains of ocean dwelling phytoplankton that died 50 million to 150 MYA.

Petroleum

Advantages

- ❑ Convenient to transport
- ❑ Relatively energy-dense
- ❑ Cleaner-burning than coal
- ❑ Produces only about 85% of CO_2 of coal per every joule of energy released

Disadvantages

- ❑ Contains sulfur and trace metals such as mercury, lead, and arsenic
- ❑ Oil must be extracted from under the ground or beneath the ocean, creating a potential for a leak or spill (*Exxon Valdez* and *Deepwater Horizon*)
- ❑ Railway accidents due to increased domestic drilling for oil
- ❑ Humans and wildlife harmed during extraction

Natural Gas

80-95 percent methane (CH_4)
5 - 20 percent ethane, propane, and butane

Two largest uses in the United States are electricity generation and industrial processes. It’s also used to manufacture nitrogen fertilizer, used in homes for cooking, heating, and operating dryers and water heaters.

Natural Gas

Advantages

- Extensive natural gas pipelines in the U.S.
- Fewer impurities and emits almost no sulfur dioxide or particulates during combustion
- For every joule of energy released during combustion, natural gas only emits 60 percent of the amount of CO_2 that coal does
- Cleanest of fossil fuels
- Can be supplied by pipeline

Disadvantages

- Unburned methane escapes into the atmosphere (greenhouse gas)
- Involves "thumper trucks" and fracking, which uses unnamed chemicals with unknown effects
- Uses large quantities of water with fracking
- Groundwater contamination
- Gas escapes during extraction (~2-9 percent)

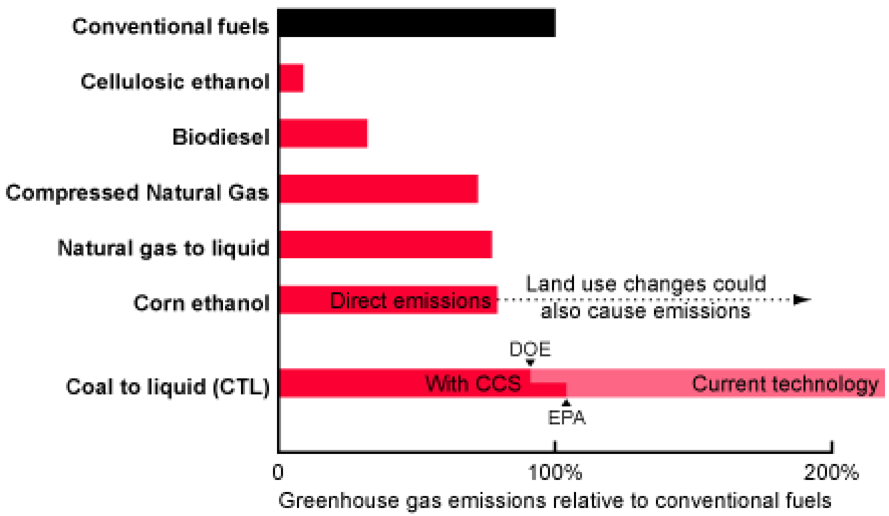
Oil Sands and Liquified Coal

Oil sands are slow-flowing, viscous deposits of *bitumen* mixed with sand, water, and clay. **Bitumen** is a degraded type of petroleum that forms with petroleum deposit is not capped with nonporous rock.

The mining of bitumen is more energy-intensive than conventional drilling for crude oil. It also contaminates 2 to 3 L of water for every liter of bitumen obtained. The overall efficiency is lower and releases a greater amount of CO_2.

Oil Sands and Liquified Coal

CTL (coal to liquid) is a type of technology that converts solid coal into liquid fuel. It was widely used by the Germans during WWII and has been used by other countries since then. However, this process is relatively expensive and features similar drawbacks that oil sand does. Even there is are more coal reserves than oil reserves (about 1,000 times greater!) the EPA estimates that that total greenhouse gas emissions from liquefied coal are more than twice those from conventionally produced oil.



Fossil Fuels Are Finite

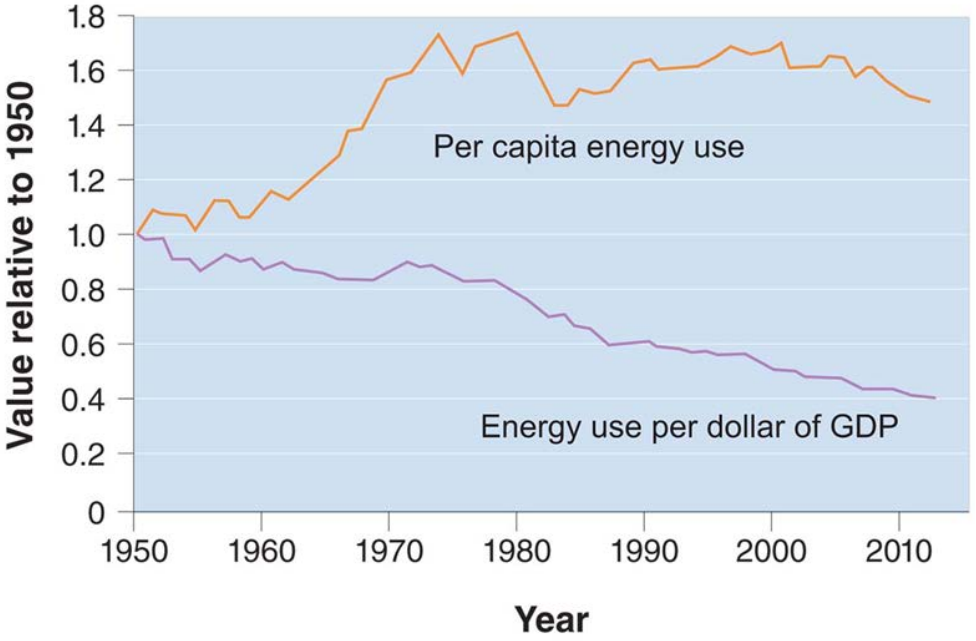


Figure 35.7
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Data from U.S. Department of Energy, Energy Information Administration, 2013

Energy intensity is the energy use per unit of gross domestic product (GDP). In recent decades in the United States energy intensity is been steadily decreasing. However, energy use overall has leveled out and not decreased due to increase in population and doing things that use energy.

The Hubbert Curve

Even though we consider fossil fuels finite resources, many environmental scientists are more concerned with adverse effects us using them as opposed to running out. In 1969, M. King Hubbert published a graph showing a bell-shaped curve representing oil use. The **hubbert curve** represents an estimation of when world oil production will reach a maximum and when world oil will finally be depleted.

Two estimates are used: an upper and lower estimate

He found that the total reserves did not greatly influence the time it would take to use up all of the oil in the known reserves.

The Hubbert Curve

Hubbert predicted that oil extraction and use would increase steadily until roughly half the supply has been used up, a point known as **peak oil**, then extraction and use would begin to decline.

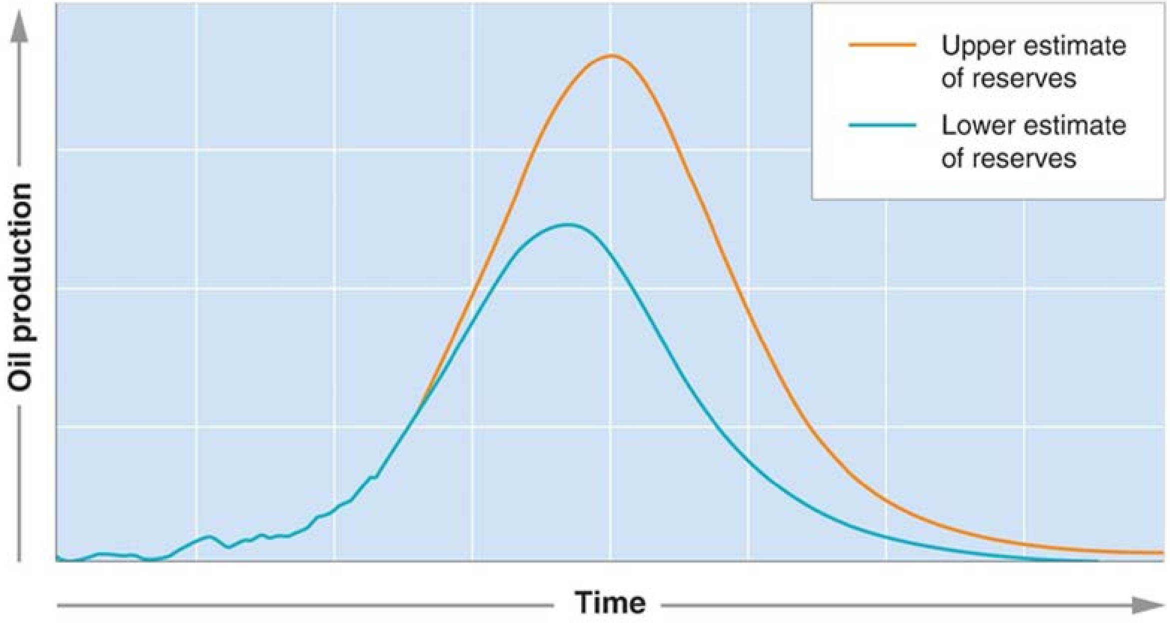
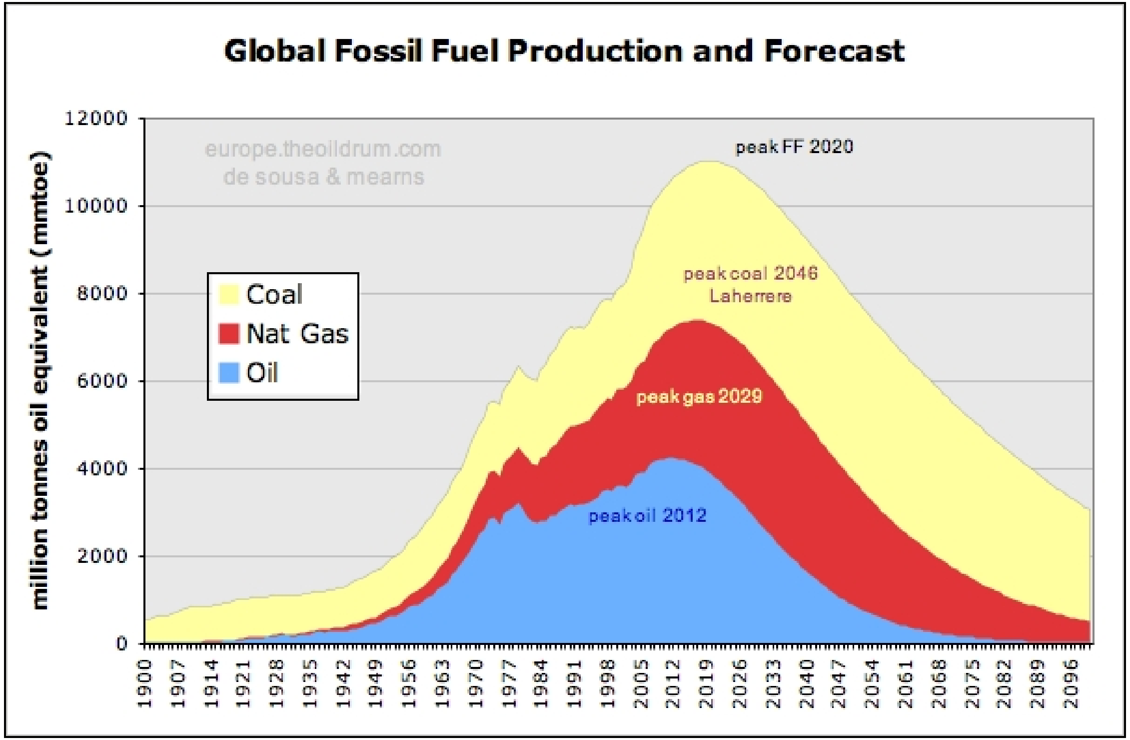


Figure 35.8
Environmental Science, Second Edition
After M. K. Hubbert, "The energy resources of the Earth," in Energy and Power, A Scientific American Book [W. H. Freeman, 1971]

The Future of Fossil Fuels

If current global use patterns continue and no significant additional oil supplies are discovered, we may run out of conventional oil supplies in less than 50 years. Natural gas will last longer and coal supplies will last for at least 200 years, probably much longer.



Module 35: Nuclear Energy Resources

After this module you will be able to……

1) Describe how nuclear energy is used to generate electricity
2) Discuss the advantages and disadvantages of using nuclear fuels to generate electricity

Nuclear Reactors and Fission

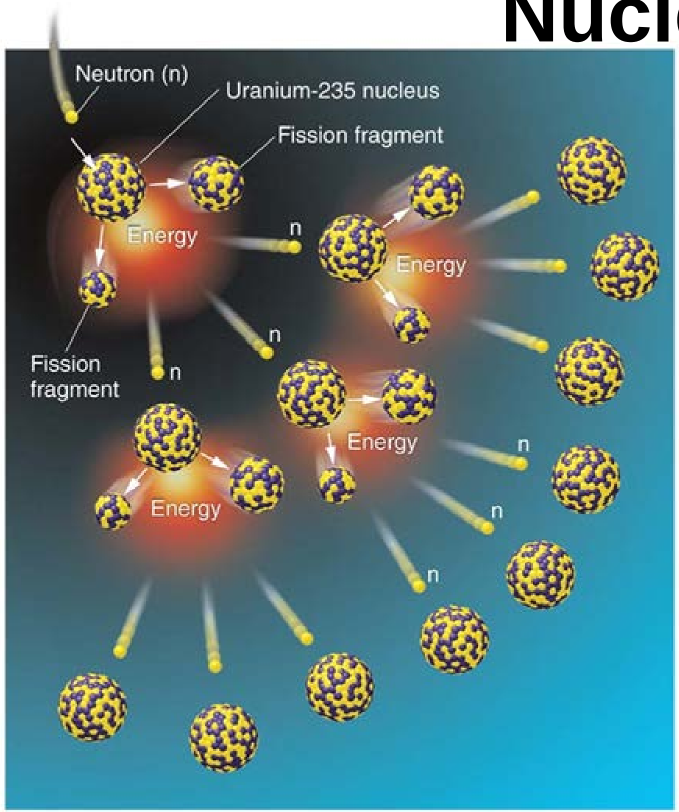


Figure 36.1
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Electricity generation from nuclear energy uses the same basis process as electricity generation from fossil fuels. However, nuclear power plants use a radioactive isotope, uranium-235 (^{235}U) as its fuel source.

Fission is a nuclear reaction in which a neutron strikes a relatively large atomic nucleus, which then splits into two or more parts, releasing additional neutrons and energy in the form of heat. Note that 1 g of ^{235}U contains 2 to 3 million times more energy than 1 g of coal.

Nuclear Reactors and Fission

The reaction for Uranium-235 fission is as follows:

1 neutron + $^{235}U \rightarrow {}^{142}Ba + {}^{91}Kr$ + 3 neutrons in motion (kinetic energy)

A nuclear reactor will harness the kinetic energy from the three neutrons in motion to produce a self-sustaining chain reaction of nuclear fission. The by-products of the nuclear reaction include radioactive waste that remains hazardous for many half-lives, which in this case is hundreds of thousands of years or longer.

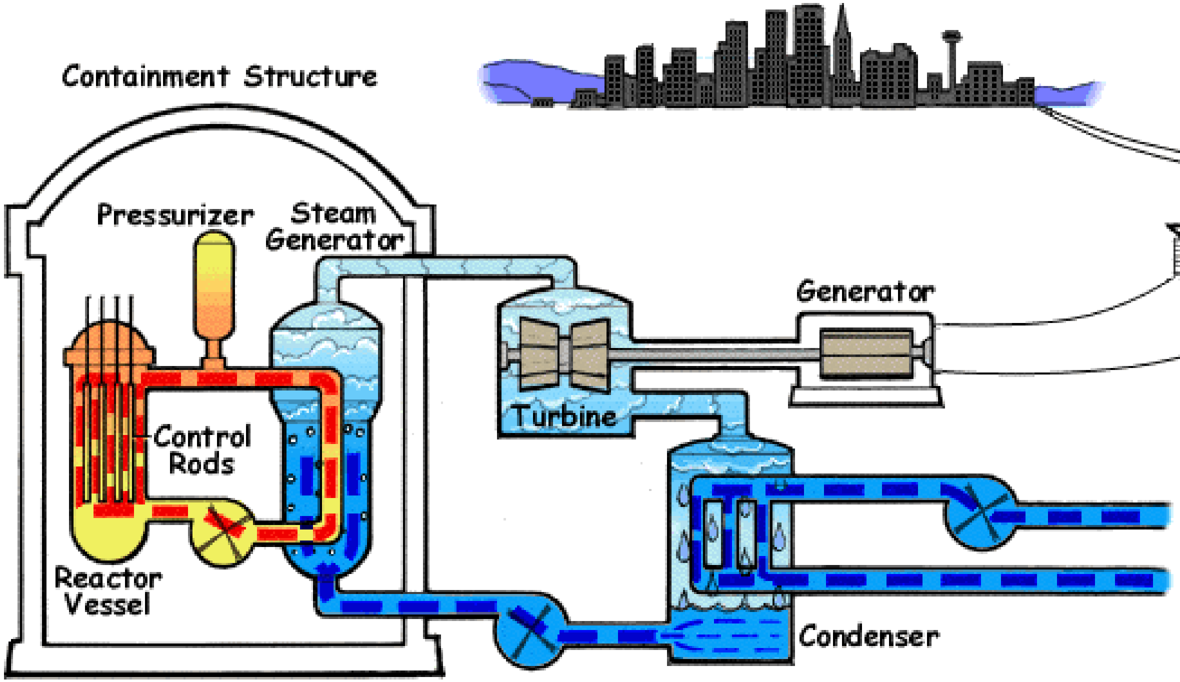
Nuclear Reactors and Fission

Fuel rods are cylindrical tubes that enclose nuclear fuel within a nuclear reactor.

A **control rod** is a cylindrical device inserted between the fuel rods in a nuclear reactor to absorb excess neutrons and slow or stop the fission reaction.

Uranium fuel is processed into pellets and put into the fuel rods. Heat from the nuclear fission is used to heat water within the containment structure, which circulates in a loop. Heat from that loop is transferred to another loop, which produces steam and turns a turbine, which turns a generator.

Nuclear Reactors and Fission



Nuclear Energy

Advantages

- Produces no air pollution ("Clean" energy)
- Countries with limited fossil fuel resources can achieve independence
- Very efficient and cheap to process

Disadvantages

- Construction of nuclear power plants can be expensive
- Concerns of nuclear accidents releasing radioactivity into the surrounding air and water
- Disposing of radioactive waste

Nuclear Accidents

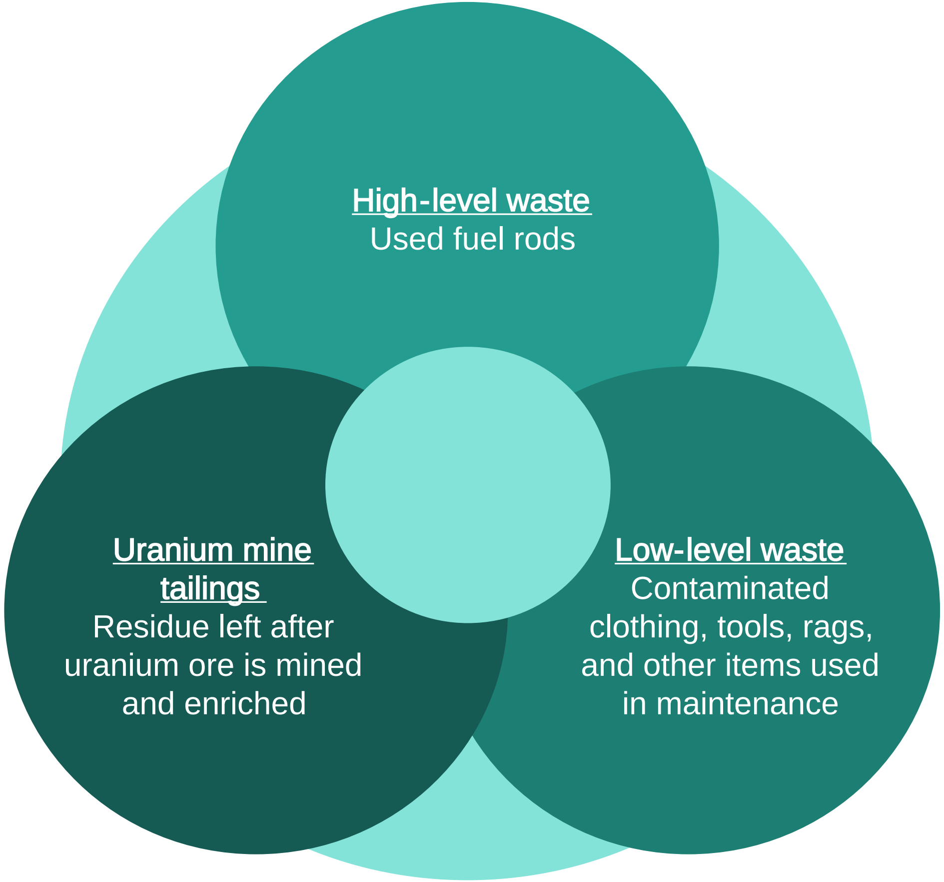
On March 28, 1979, the Three Mile Island nuclear power plant in Pennsylvania overheated and released a large amount of radiation to the outside environment. This caused over 200,000 people to evacuate.

On April 26, 1986, a serious accident occurred in Chernobyl, Ukraine. An explosion occurred that killed 31 plant workers and firefighters from acute radiation exposure and burns and many more deaths occurred later due to exposure.

On March 11, 2011 a power plant in Japan was flooded due to a tsunami. Radioactive gases from nuclear reactors were leaked into the environment and over 100,000 people were evacuated. After this accident, Japan shut down all 54 of its nuclear reactors, with 5 being restarted as of mid 2018.



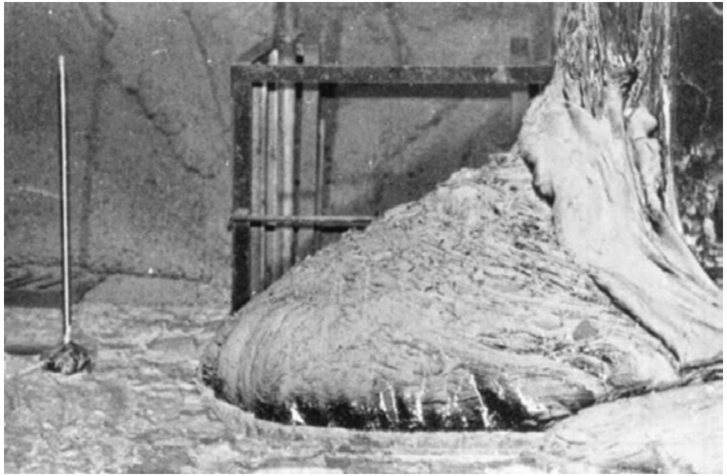
Radioactive Waste



Radioactive waste is nuclear fuel that can no longer produce enough heat to be useful in a power plant but continues to emit radioactivity. Nuclear fuels produce three kinds of radioactive waste.

Radioactive Waste

HIGH-LEVEL	LOW-LEVEL
• ↑ doses can cause organ immediate damage including organ failure, radiation sickness, and death • ↓ doses can cause the same symptoms of low-level radiation	• Can cause damage to DNA which may ultimately lead to cancer and tumors • Sublethal harmful effects to the eyes, brain, and immune and reproductive system



Known as the “elephant’s foot”, a large and highly radioactive waste after the Chernobyl disaster.

Half-Life

Uranium-235 has a half-life of 704,000,000 years. This means that 704 million years from today, the same piece of ^{235}U will only be half as radioactive as it is today. Radiation can be measured in a variety of units.

Becquerel (Bq) measures the rate at which a sample of radioactive material decays. 1 Bq is equal to the decay of one atom per second.

Curie is another measure of radiation; 1 curie = 37 billion decays per second. 100 curies has a half-life of 50 years.

Half-Life

Example

Strontium-90 is a radioactive waste product from nuclear reactors. It has a half-life of 29 years. How many years will it take for a quantity of strontium-90 to decay to 1/16 of its original mass?

It will take 29 years to decay to ½ its original mass; another 29 years to ¼; another 29 years to ⅛; and another 29 years to 1/16:

29 x 4 = 116 years.

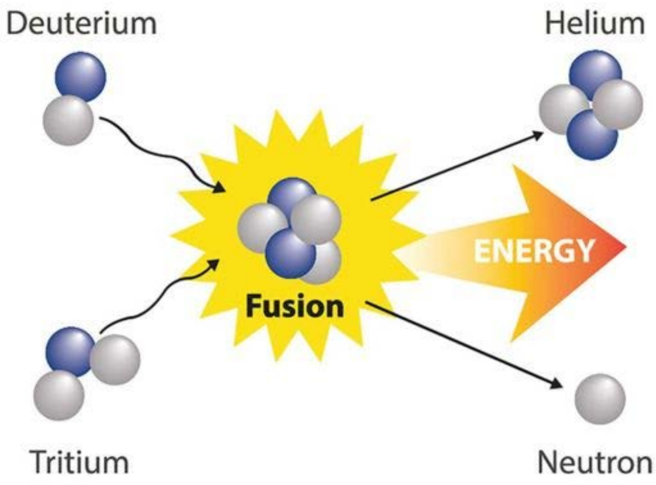
Your turn…

You have 180 g of a radioactive substance. It has a half-life of 265 years. After 1,325 years, what mass remains?

Storing Radioactive Materials

Currently, power plants are required to store spent fuel rods at the plant itself. Initially, all fuel rods are stored in pools of water at least 6 m deep since the water acts as a shield from radiation. There are more than 100 sites around the country that are storing their fuel rods and pool storage is running low. Now they are storing the rods in lead-lined dry containers on land.

Fusion Power



Recall that nuclear fission occurs when the nuclei of radioactive atoms are broken apart into smaller, lighter nuclei. **Nuclear fusion**, the reaction that powers the Sun and other stars, occurs when lighter nuclei are forced together to produce heavier nuclei. This process generates a great deal of heat. The most promising nuclear fusion reaction for electricity generation is two hydrogen isotopes fusing together into a helium atom. The reaction loses a small amount of mass and and releases a tremendous amount of energy.

Fusion Power

Nuclear fusion has a seemingly unlimited source of energy that requires only hydrogen as an input and produces relatively small amounts of radioactive waste. However, to create this fusion on Earth we need a reactor that will heat material to temperatures 10 times those in the core of the sun. This is extremely difficult to contain and most experts believe we will not be able to use this as a reliable source for at least several decades.