KEY ISSUE 3

Why Are Energy Resources Important for Development?

Learning Outcome 9.3.1
Explain the principal sources of demand for fossil fuels.

- **Energy Supply and Demand**
- **Alternative Energy Sources**

Development is based on availability of abundant low-cost energy. Developed countries use large quantities of energy to produce food, run factories, keep homes comfortable, and transport people and goods. Developing countries expect to use more energy to improve the lives of their citizens.

In Chapter 1, we distinguished between renewable resources (those produced in nature more rapidly than consumed by humans) and nonrenewable resources (those produced in nature more slowly than consumed by humans). Most of the energy resources used by humans are nonrenewable. In the long run, sustainable development will necessitate increased reliance on renewable energy.

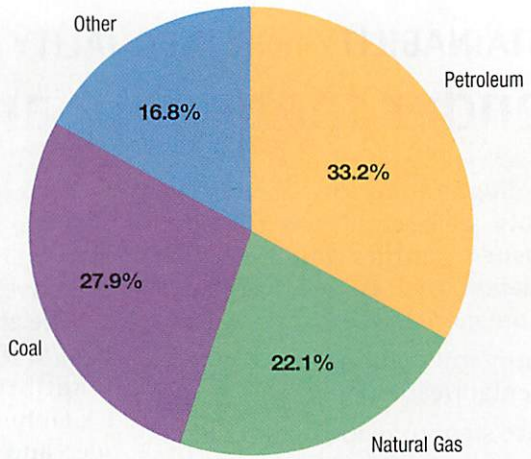
Energy Demand and Supply

Supply is the quantity of something that producers have available for sale. **Demand** is the quantity that consumers are willing and able to buy. Five-sixths of the world's energy needs are supplied by three of Earth's substances (Figure 9-25):

- **Coal.** Coal supplanted wood as the leading energy source in North America and Europe in the late 1800s, as these regions developed rapidly.
- **Petroleum.** Petroleum was first pumped in 1859 but did not become an important source of energy until the diffusion of motor vehicles in the twentieth century.
- **Natural gas.** Natural gas was originally burned off as a waste product of petroleum drilling, but it is now used to heat homes and to produce electricity.

In a developed country like the United States, dependency on these three sources of energy increased rapidly during the twentieth century (Figure 9-26).

Petroleum, natural gas, and coal are known as fossil fuels. A **fossil fuel** is an energy source formed from the residue of plants and animals buried millions of years ago. As sediment accumulated over these remains, intense pressure and chemical reactions slowly converted them into the fossil fuels that are currently used. When these substances are burned, energy that was stored in plants and animals millions of years ago is released.



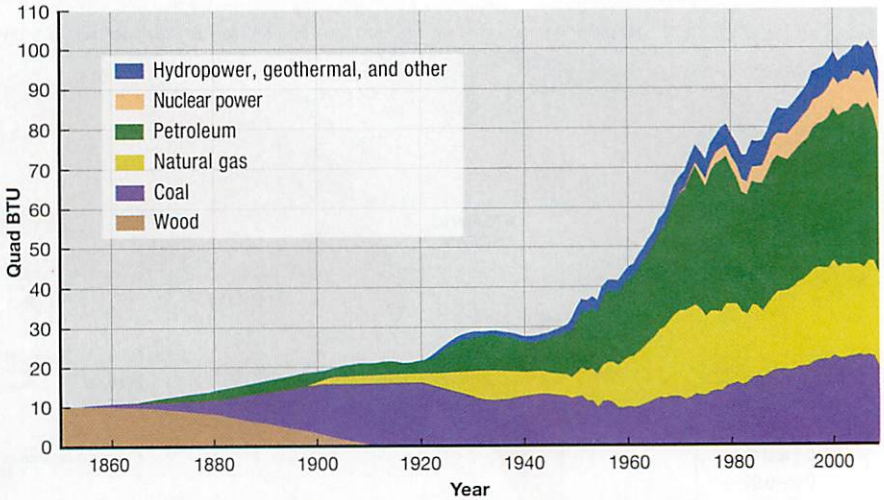
▲ FIGURE 9-25 **WORLD ENERGY DEMAND** Petroleum, coal, and natural gas account for most of the world's energy consumption.

Geographers observe two important inequalities in the global distribution of fossil fuels:

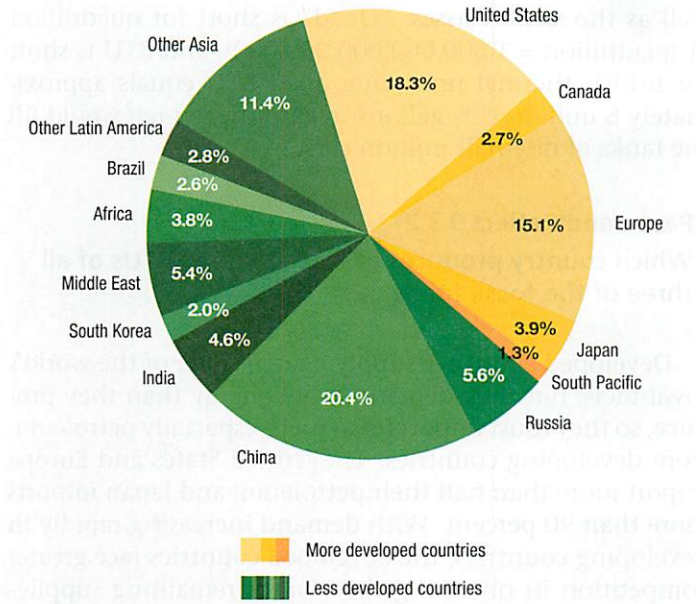
- **Demand.** The heaviest consumers of fossil fuel are in developed countries, whereas most of the reserves are in developing countries.
- **Supply.** Some developing regions have abundant reserves, whereas others have little.

Given the centrality of fossil fuels in contemporary economy and culture, unequal consumption and reserves of fossil fuels have been major sources of instability between developed and developing countries.

Pause and Reflect 9.3.1
Which energy source increased most rapidly in the United States during the twentieth century?



▲ FIGURE 9-26 **CHANGING U.S. ENERGY DEMAND** Coal was the principal energy source in the nineteenth century. Petroleum and natural gas became important in the twentieth century.



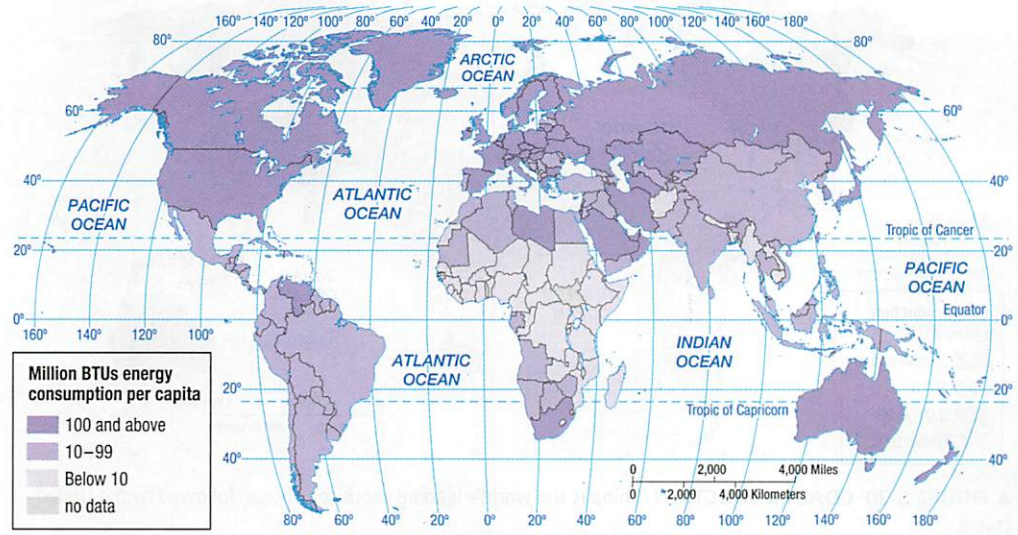
▲ **FIGURE 9-27 SHARE OF WORLD ENERGY DEMAND** Developed and developing countries each consume around one-half of the world's energy.

DEMAND FOR ENERGY

Around one-half of the world's energy is consumed in developed countries and one-half in developing countries (Figure 9-27). The United States had long been the leading consumer of energy, but China now consumes 20 percent of the world's energy, followed by the United States, at 18 percent. The highest per capita consumption of energy is in North America; the region contains one-twentieth of the world's people but consumes one-fourth of the world's energy (Figure 9-28). Developed countries contain only around one-third of the population of developing countries, so per capita consumption of energy is thus around three times higher in developed countries than in developing countries.

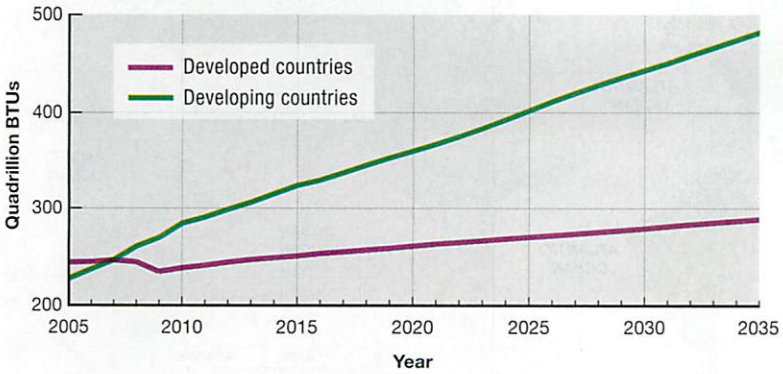
Demand for energy comes from three principal types of consumption in the United States:

- **Businesses.** The main energy demand is for coal, followed by natural gas and petroleum. Some businesses directly burn coal in their own furnaces. Others rely on electricity, mostly generated at coal-burning power plants.
- **Homes.** Energy is demanded primarily for the heating of living spaces and water. Natural gas is the most common source, followed by petroleum (heating oil and kerosene).
- **Transportation.** Almost all transportation systems demand petroleum products, including cars, trucks, buses, airplanes, and most railroads. Only subways, streetcars, and some trains run on coal-generated electricity.



▲ **FIGURE 9-28 ENERGY DEMAND PER CAPITA** The highest per capita consumption is in North America, and the lowest is in sub-Saharan Africa.

In 2007, demand for fossil fuel consumption in developing countries surpassed that of developed countries for the first time (Figure 9-29). The gap in demand between developing and developed countries is expected to widen considerably in the years ahead because consumption of fossil fuels has been increasing at a much faster rate in developing countries—around 3 percent per year, compared to 1 percent per year in developed countries. Increasing reliance on fossil fuels also undermines the goals of sustainable development.



▲ **FIGURE 9-29 FUTURE ENERGY DEMAND** Developing countries are expected to consume 62 percent of the world's energy in 2035.

ENERGY SUPPLY

Learning Outcome 9.3.2

Describe the distribution of production of the three fossil fuels.

Energy is required for development, but Earth's energy resources are not distributed evenly. Why do some regions have an abundant supply of reserves of one or more fossil fuels, but other regions have little? This partly reflects how fossil fuels form:

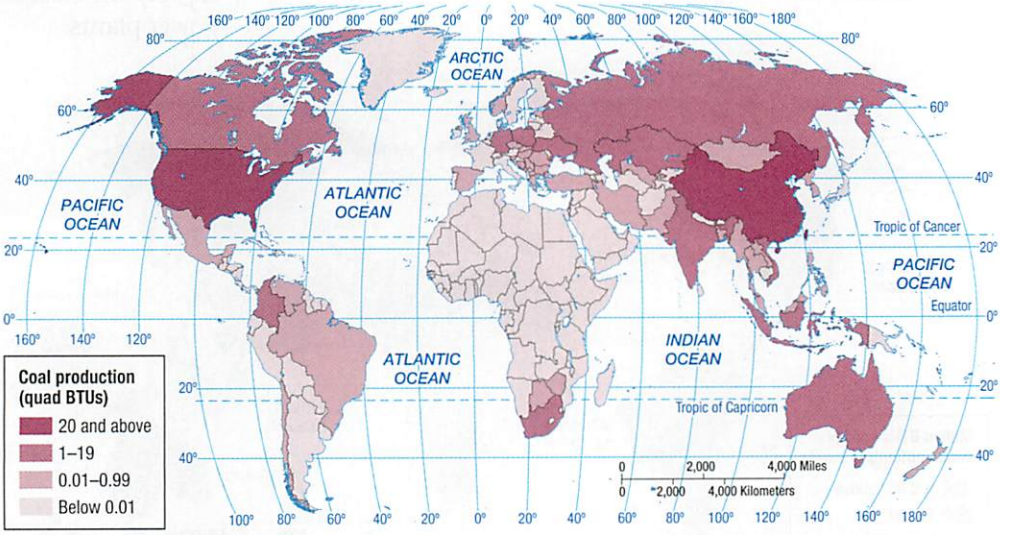
- **Coal.** Coal formed in tropical locations, in lush, swampy areas rich in plants. Thanks to the slow movement of Earth's drifting continents, the tropical swamps of 250 million years ago have relocated to the mid-latitudes. As a result, today's main reserves of coal are in mid-latitude countries rather than in the tropics. China is responsible for supplying nearly one-half of the world's coal, other developing countries one-fourth, and developed countries (primarily the United States) the remaining one-fourth (Figure 9-30).
- **Petroleum.** Petroleum formed millions of years ago from residue deposited on the seafloor. Some still lies beneath such seas as the Persian Gulf and the North Sea, but other reserves are located beneath land that was under water millions of years ago. Russia and Saudi Arabia together supply one-fourth of the world's petroleum, other developing countries (primarily in Southwest and Central Asia) one-half, and developed countries (primarily the United States) the remaining one-fourth (Figure 9-31).
- **Natural gas.** Natural gas, like petroleum, formed millions of years ago from sediment deposited on the seafloor. One-third of natural gas production is supplied by Russia and Southwest Asia, one-third by other developing regions, and one-third by developed countries (primarily the United States) (Figure 9-32). Within the United States, the principal natural gas fields are in Texas, Oklahoma, and the Appalachian Mountains (Figure 9-33).

Figures 9-30, 9-31, and 9-32 use the same units (quad BTU), as well as the same classes. "Quad" is short for quadrillion (1 quadrillion = 1,000,000,000,000,000), and BTU is short for British thermal unit. One quad BTU equals approximately 8 million U.S. gallons of gasoline, which would fill the tanks of one-half million cars.

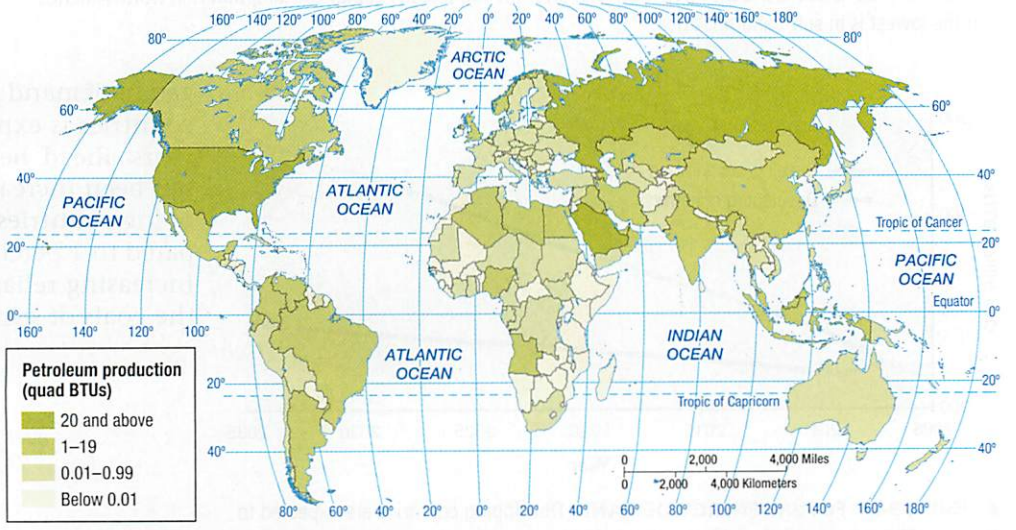
Pause and Reflect 9.3.2

Which country produces at least 20 quad BTUs of all three of the fossil fuels?

Developed countries supply a large share of the world's fossil fuels, but they demand more energy than they produce, so they must import fossil fuels, especially petroleum, from developing countries. The United States and Europe import more than half their petroleum, and Japan imports more than 90 percent. With demand increasing rapidly in developing countries, the developed countries face greater competition in obtaining the world's remaining supplies of fossil fuels. Many of the developing countries with low



▲ **FIGURE 9-30 COAL PRODUCTION** China is the world's leading producer of coal, followed by the United states.

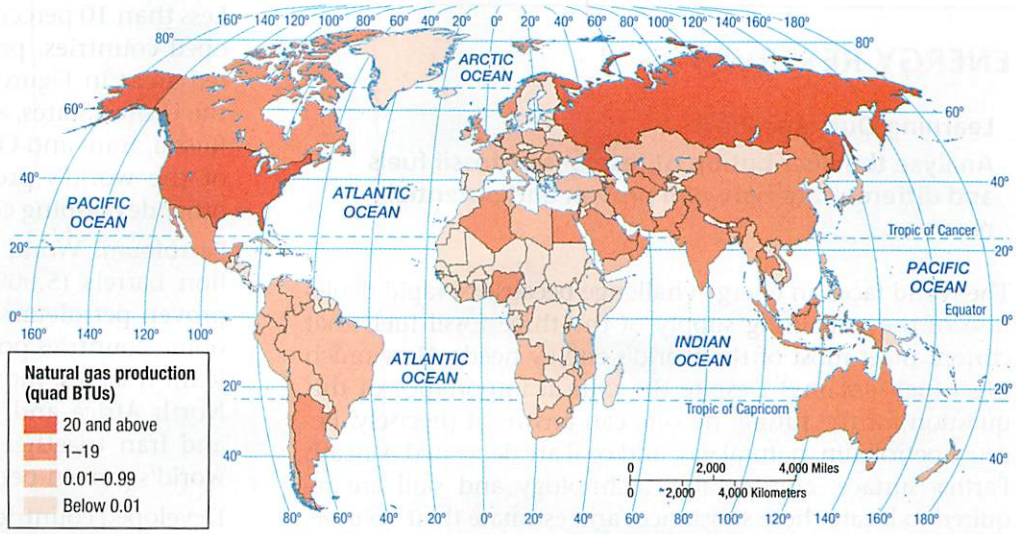


▲ **FIGURE 9-31 PETROLEUM PRODUCTION** Russia, Saudi Arabia, and the United States are the leading producers of petroleum.

HDIs also lack energy resources, and they lack the funds to pay for importing them.

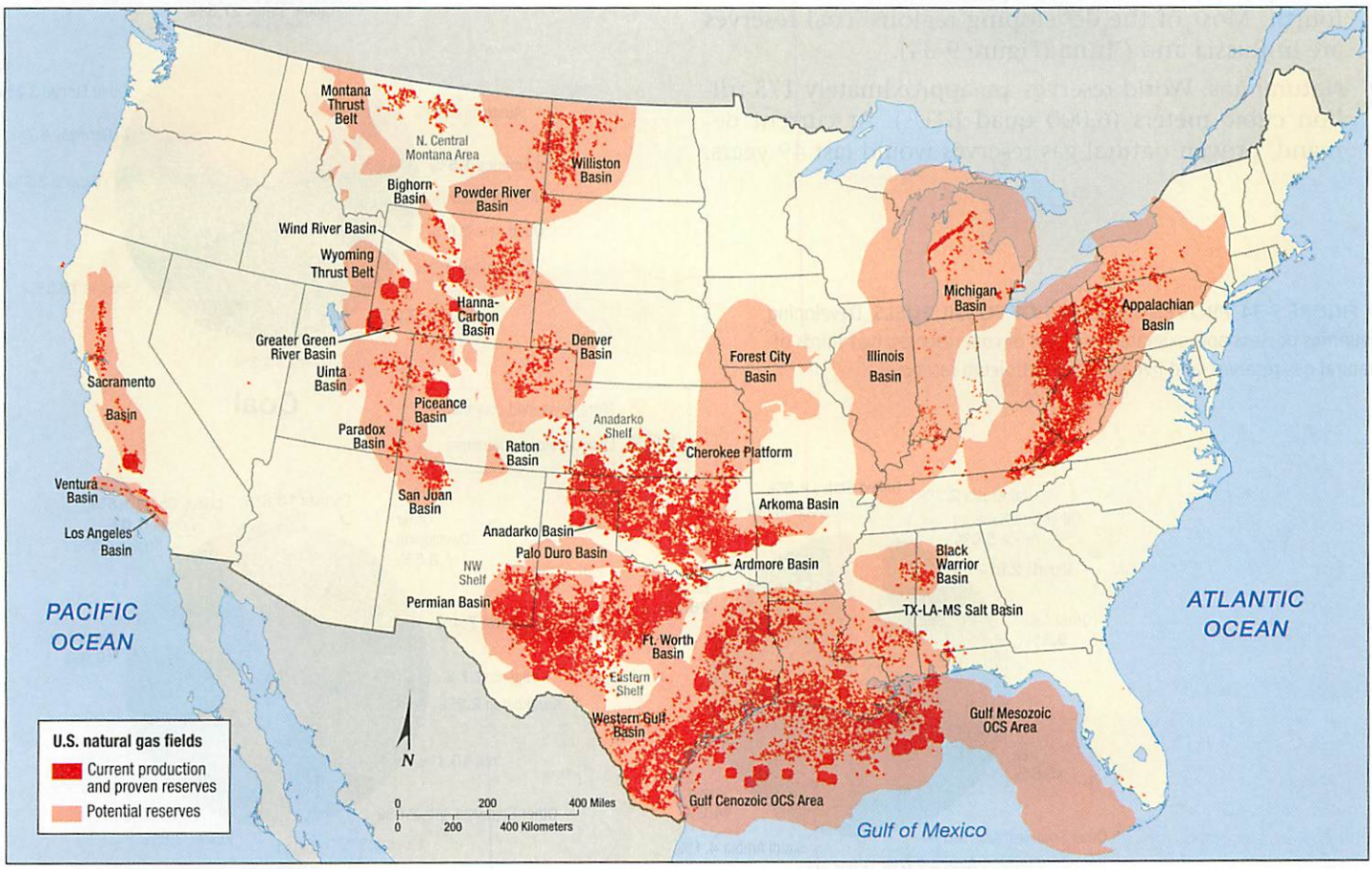
Compounding future energy challenges, Earth's energy resources are divided between those that are renewable and those that are not:

- **Renewable energy** has an essentially unlimited supply and is not depleted when used by people. Examples include hydroelectric, geothermal, fusion, wind, biomass, and solar energy.
- **Nonrenewable energy** forms so slowly that for practical purposes, it cannot be renewed. Examples are the three fossil fuels that currently supply most of the world's energy needs.



▲ **FIGURE 9-32 NATURAL GAS PRODUCTION** The United States and Russia are the leading producers of natural gas.

Because of dwindling supplies of fossil fuels, most of the buildings in which people live, work, and study will have to be heated another way. Cars, trucks, and buses will have to operate on some other energy source. Because plastic is made from petroleum, objects made of plastic will have to be made from other materials. Other resources can be used for heat, fuel, and manufacturing, but they are likely to be more expensive and less convenient to use than fossil fuels. And converting from fossil fuels will likely disrupt daily lives and cause hardship. On the other hand, the search for alternatives to fossil fuels may also create development opportunities.



▲ **FIGURE 9-33 NATURAL GAS FIELDS IN THE UNITED STATES** The principal natural gas fields are in Oklahoma, Texas, and the Appalachians.

ENERGY RESERVES

Learning Outcome 9.3.3

Analyze the distribution of reserves of fossil fuels and differentiate between proven and potential reserves.

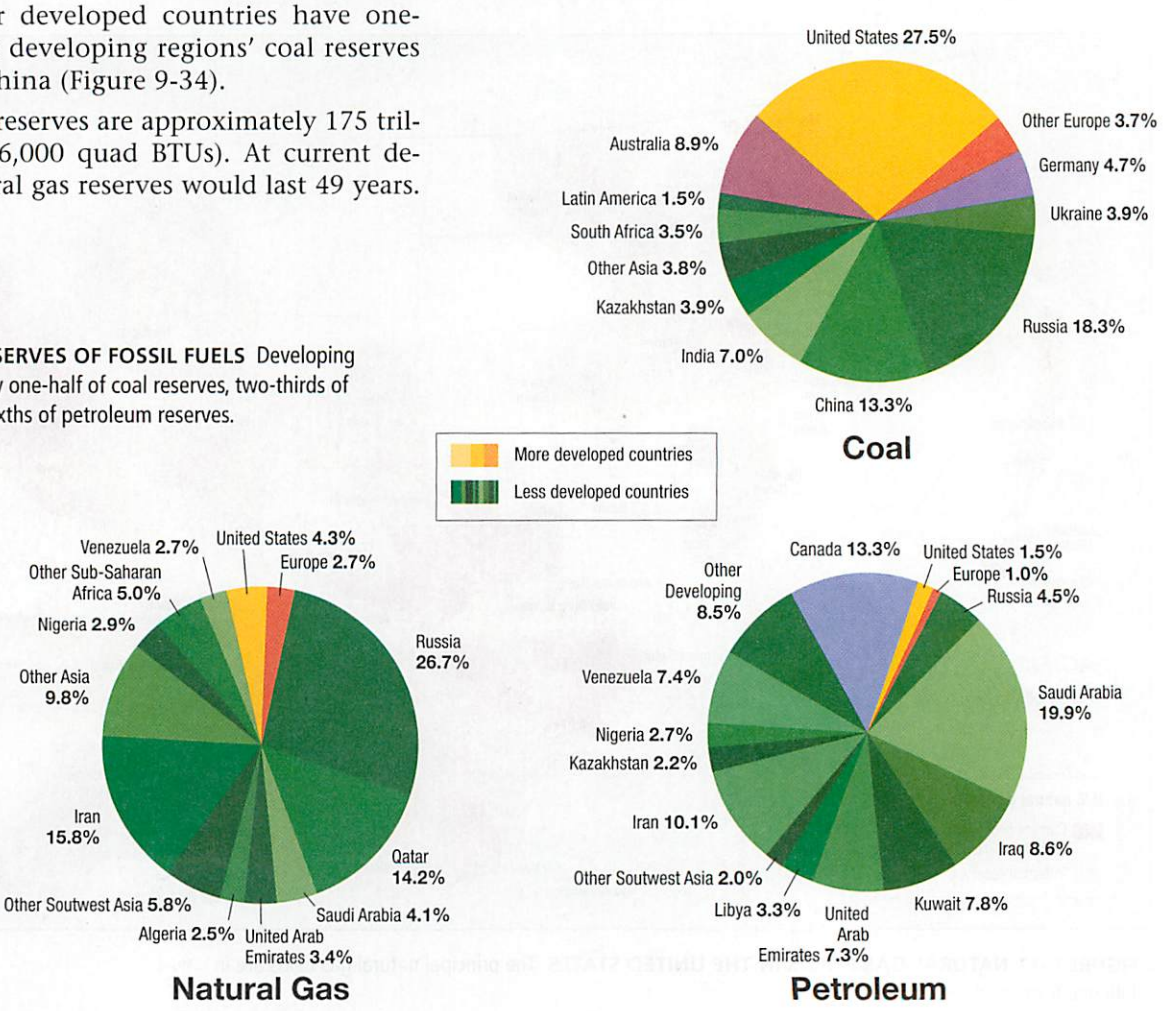
The world faces an energy challenge because of rapid depletion of the remaining supply of the three fossil fuels that current meet most of the world's energy needs. How much fossil fuel remains? Despite the critical importance of this question for the future, no one can answer it precisely. Because petroleum, natural gas, and coal are deposited beneath Earth's surface, considerable technology and skill are required to locate these substances and estimate their volume.

PROVEN RESERVES. The supply of energy remaining in deposits that have been discovered is called a **proven reserve**. Proven reserves can be measured with reasonable accuracy:

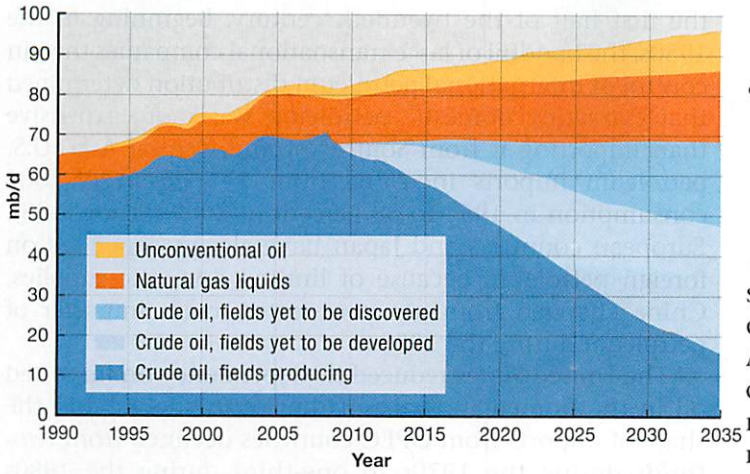
- **Coal.** World reserves are approximately 1 quadrillion metric tons (23 million quad BTUs). At current demand, proven coal reserves would last 131 years. Developed and developing regions each have about one-half of the supply of proven reserves. The United States has approximately one-fourth of the proven reserves, and other developed countries have one-fourth. Most of the developing regions' coal reserves are in Russia and China (Figure 9-34).
- **Natural gas.** World reserves are approximately 175 trillion cubic meters (6,000 quad BTUs). At current demand, proven natural gas reserves would last 49 years. Less than 10 percent of natural gas reserves are in developed countries, primarily the United States. The dark red areas in Figure 9-33 show proven reserve fields in the United States, as well as areas of current production. Russia, Iran, and Qatar together have nearly 60 percent of the world's proven natural gas reserves, and five other developing countries have most of the remainder.
- **Petroleum.** World reserves are approximately 1.3 trillion barrels (5,000 quad BTUs). At current demand, proven petroleum reserves would last 43 years. Developing countries possess 85 percent of the proven petroleum reserves, most of which is in Southwest Asia and North Africa and Central Asia. Saudi Arabia, Canada, and Iran together have more than 40 percent of the world's proven petroleum reserves.

Developed countries have historically possessed a disproportionately high supply of the world's proven fossil-fuel reserves. Europe's nineteenth-century industrial development depended on its abundant coal fields, and extensive coal and petroleum supplies helped the United States become the leading industrial power of the twentieth century.

But this dominance is ending in the twenty-first century. Many of Europe's coal mines have closed because either the coal has been exhausted or extracting the remaining supply would be too expensive, and the region's



▼ **FIGURE 9-34 PROVEN RESERVES OF FOSSIL FUELS** Developing countries possess approximately one-half of coal reserves, two-thirds of natural gas reserves, and five-sixths of petroleum reserves.



▲ **FIGURE 9-35 PETROLEUM PRODUCTION OUTLOOK** The International Energy Agency forecasts that potential reserves will be converted to proven reserves through discovery and development of new fields at about the same rate as already proven reserves are depleted.

petroleum and natural gas (in the North Sea) account for only small percentages of worldwide supplies. Japan has never had significant fossil fuel reserves. The United States still has extensive coal reserves, but its petroleum and natural gas reserves are being depleted rapidly.

Pause and Reflect 9.3.3

No country ranks among the leaders in proven reserves in all three fossil fuels. Which two countries possess at least 10 percent of the proven reserves of two of the three fossil fuels?

POTENTIAL RESERVES. Some fossil fuel deposits have not yet been discovered. The supply in deposits that are undiscovered but thought to exist is a **potential reserve**. When a potential reserve is actually discovered, it is reclassified as a proven reserve (Figure 9-35). Potential reserves can be converted to proven reserves in several ways:

- **Undiscovered fields.** The largest, most accessible deposits of petroleum, natural gas, and coal have already been exploited. Newly discovered reserves are generally smaller and more remote, such as beneath the seafloor, and extraction is costly. Exploration costs have increased because methods are more elaborate and the probability of finding new reserves is less. But as energy prices climb, exploration costs may be justified.
- **Enhanced recovery from already discovered fields.** When it was first exploited, petroleum "gushed" from wells drilled into rock layers saturated with it. Coal was quarried in open pits. But now extraction is more difficult. Sometimes pumping is not sufficient to remove petroleum, but water or carbon dioxide may be forced into wells to push out the remaining resource. The problem of removing the last supplies from a proven field is comparable to wringing out a soaked towel. It is easy to quickly remove the main volume of water, but the last few percent require more time and patience and special technology.
- **Unconventional sources.** Some sources are called unconventional because methods currently used to extract resources won't work. Also, we do not currently have economically feasible, environmentally sound technology with which to extract these sources.

An important example of an unconventional source is oil sands, which are saturated with a thick petroleum commonly called tar because of its dark color and strong odor. Native Americans used the tar to caulk canoes in the eighteenth century. The oil must be extracted from the sands through mining, which can be environmentally damaging, and current technology makes processing expensive. Abundant oil sands are found in Alberta, Canada, as well as in Venezuela and Russia. As demand has increased for petroleum, and as prices have risen, the mining of Alberta oil sands has become profitable, and extensive deposits of oil in Alberta oil sands have been reclassified from potential to proven reserves in recent years (Figure 9-36). As a result, Canada is now thought to have 13 percent of world's petroleum proven reserves, second behind Saudi Arabia, although overall oil sands are still classified as unconventional sources.

Another important unconventional source that has been increasingly exploited in recent years is extraction of natural gas through hydraulic fracturing, commonly called **fracking**. Rocks break apart naturally, and gas can fill the space between the rocks. Fracking involves pumping water at high pressure to further break apart rocks and thereby release more gas that can be extracted. Opponents of fracking fear environmental damage from pumping high-pressure water beneath Earth's surface. Safety precautions can minimize the environmental threat, but fracking does require the use of a large supply of water, and water is in high demand for other important uses, such as human consumption and agriculture.

▲ **FIGURE 9-36 CANADA'S OIL SANDS** Canada has the world's second-largest proven reserves of petroleum, which must be extracted from oil sands in Alberta.

CONTROLLING PETROLEUM RESERVES

Learning Outcome 9.3.4

Describe the role of OPEC and changes in the price and availability of petroleum.

Developed countries import most of their petroleum from Southwest Asia & North Africa and Central Asia, where most of the world's proven reserves are concentrated. These regions are the center of ethnic and political conflicts, as discussed in Chapters 7 and 8.

OPEC. Several developing countries possessing substantial petroleum reserves created the Organization of the Petroleum Exporting Countries (OPEC) in 1960. Arab OPEC members in Southwest Asia & North Africa include Algeria, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, and the United Arab Emirates. OPEC members in other regions include Angola, Ecuador, Iran, Nigeria, and Venezuela.

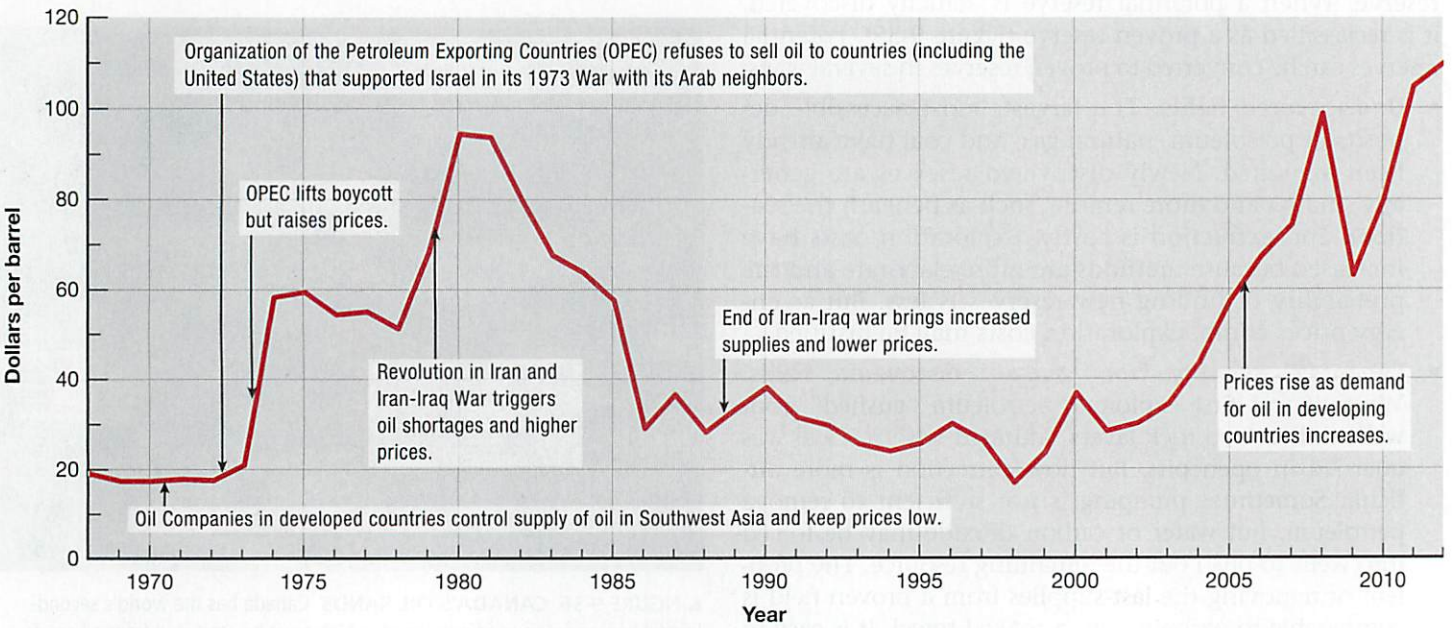
OPEC was originally formed to enable oil-rich developing countries to gain more control over their resource. U.S. and European transnational companies, which had originally explored and exploited the oil fields, were selling the petroleum at low prices to consumers in developed countries and keeping most of the profits. Countries possessing the oil reserves nationalized or more tightly controlled the fields, and prices were set by governments rather than by petroleum companies. Under OPEC control, world oil prices have increased sharply on several occasions, especially during the 1970s and 1980s and in the early twenty-first century (Figure 9-37).

CHANGING U.S. PETROLEUM SOURCES. The United States produced more petroleum than it consumed during the first half of the twentieth century. Beginning in the 1950s, the handful of large transnational companies then in control of international petroleum distribution determined that extracting domestic petroleum was more expensive than importing it from Southwest and Central Asia. U.S. petroleum imports increased from 14 percent of total consumption in 1954 to 58 percent in 2009 (Figure 9-38). European countries and Japan have always depended on foreign petroleum because of limited domestic supplies. China changed from a net exporter to an importer of petroleum during the 1990s.

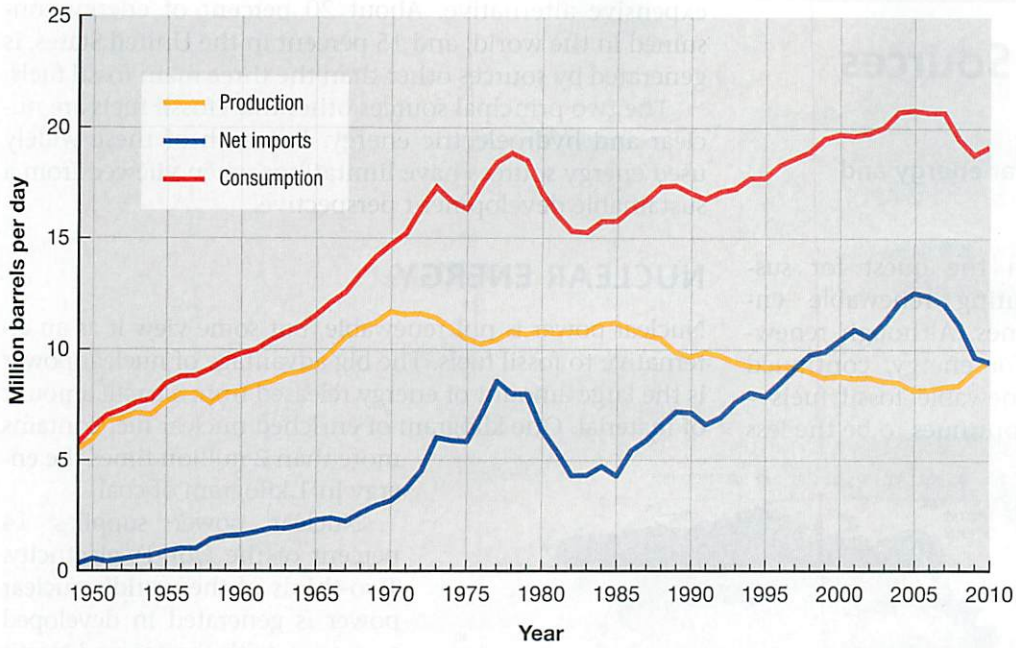
The United States reduced its dependency on imported oil in the immediate wake of the 1970s shocks, and the share of imports from OPEC countries declined from two-thirds during the 1970s to one-third during the 1980s (Figure 9-39). Conservation measures also dampened demand for petroleum in most developed countries during the late twentieth century. The average vehicle driven in the United States, for example, got 14 miles per gallon in 1975, compared to 22 miles per gallon in 1985.

The price of petroleum plummeted during the 1980s and settled during the 1990s at the lowest level in modern history, adjusting for inflation (Figure 9-40). With petroleum prices remaining low into the twenty-first century, consumption increased. Americans bought more gas-guzzling trucks and sport-utility vehicles and drove longer distances. Developed countries entered the twenty-first century optimistic that oil prices would remain low for some time. But in 2008, prices hit a record high, in both real terms and accounting for inflation. The 2008 oil shock contributed to the severe global recession that began then.

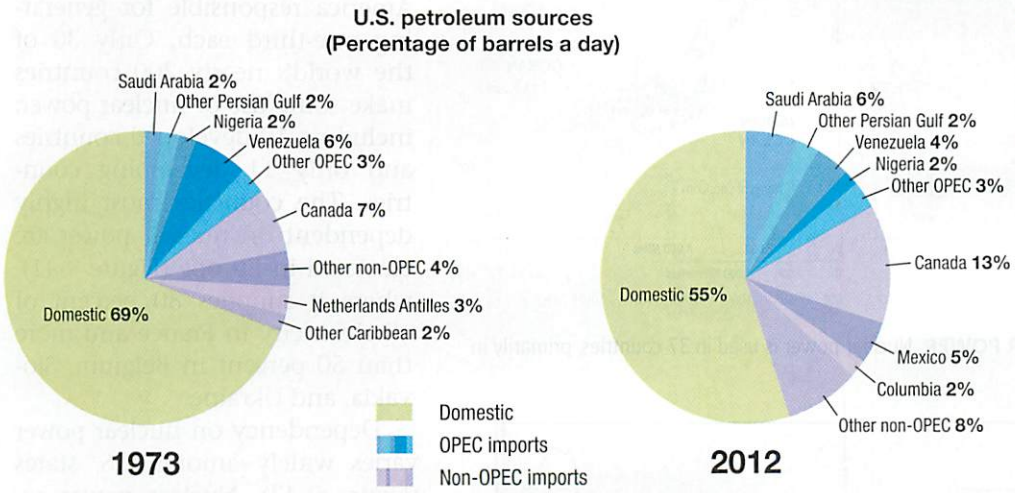
The world will not literally "run out" of petroleum during the twenty-first century. However, at some point, extracting the remaining petroleum reserves will prove so expensive and environmentally damaging that use of



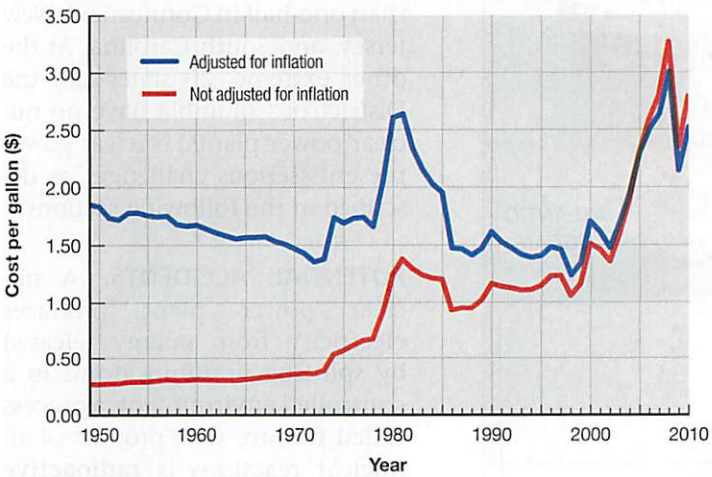
▲ FIGURE 9-37 **OIL PRICE HISTORY** Oil prices have increased sharply on several occasions.



◀ **FIGURE 9-38 U.S. PETROLEUM CONSUMPTION, PRODUCTION, AND IMPORTS** U.S. production has remained relatively constant since the 1960s. Increasing consumption has been served by increasing imports.



◀ **FIGURE 9-39 U.S. PETROLEUM SOURCES** The United States imports a higher percentage of petroleum now than in the 1970s. The increase has come primarily from elsewhere in the Western Hemisphere.



▲ **FIGURE 9-40 U.S. GASOLINE PRICES** The line adjusted for inflation is in 2005 dollars.

alternative energy sources will accelerate, and dependency on petroleum will diminish. The issues for the world are whether dwindling petroleum reserves are handled wisely and other energy sources are substituted peacefully. Given the massive growth in petroleum consumption expected in developing countries such as China and India, the United States and other developed countries may have little influence over when prices rise and supplies decline. In this challenging environment, all countries will need to pursue sustainable development strategies based on increased reliance on renewable energy sources.

Pause and Reflect 9.3.4

What country exports the most petroleum to the United States?

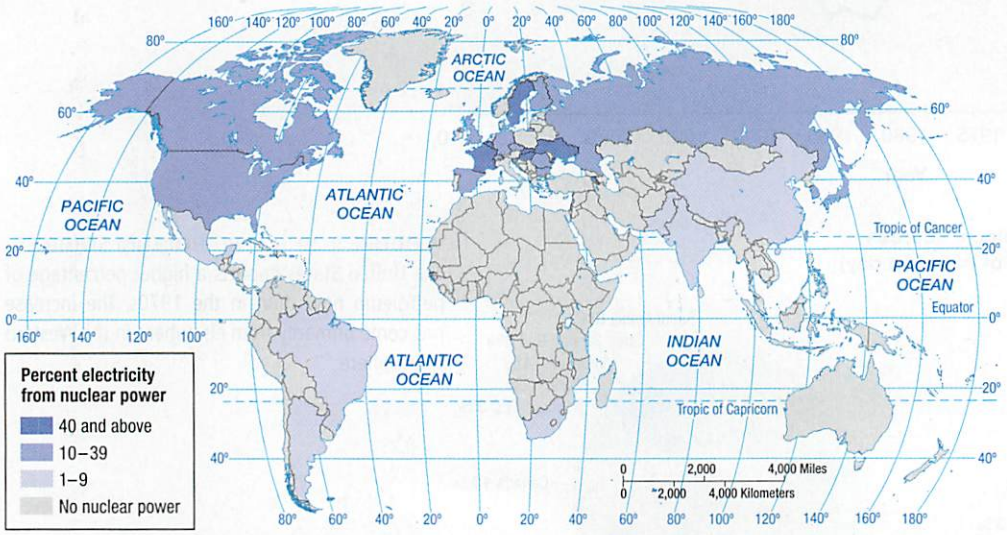
Alternative Energy Sources

Learning Outcome 9.3.5

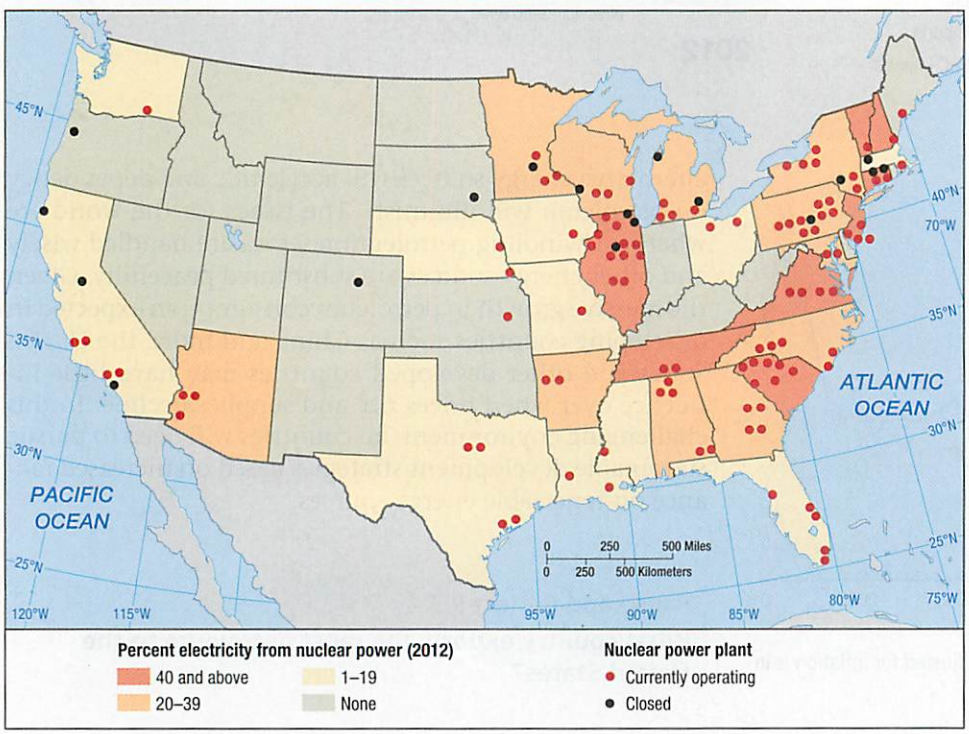
Describe the distribution of nuclear energy and challenges in using it.

An especially strong challenge in the quest for sustainable development is substituting renewable energy resources for nonrenewable ones. Although renewable resources can be harnessed for energy, continued reliance on the three main nonrenewable fossil fuels—petroleum, natural gas, and coal—continues to be the less expensive alternative. About 20 percent of energy consumed in the world, and 15 percent in the United States, is generated by sources other than the three main fossil fuels.

The two principal sources other than fossil fuels are nuclear and hydroelectric energy. But both of these widely used energy sources have limitations when viiewed from a sustainable development perspective.



▲ **FIGURE 9-41 ELECTRICITY FROM NUCLEAR POWER** Nuclear power is used in 37 countries, primarily in Europe and North America.



▲ **FIGURE 9-42 NUCLEAR POWER BY U.S. STATE** One-third of electricity is generated from nuclear power in the Northeast, compared to less than one-tenth in the West.

NUCLEAR ENERGY

Nuclear power is not renewable, but some view it as an alternative to fossil fuels. The big advantage of nuclear power is the large amount of energy released from a small amount of material. One kilogram of enriched nuclear fuel contains more than 2 million times the energy in 1 kilogram of coal.

Nuclear power supplies 14 percent of the world's electricity. Two-thirds of the world's nuclear power is generated in developed countries, with Europe and North America responsible for generating one-third each. Only 30 of the world's nearly 200 countries make some use of nuclear power, including 19 developed countries and only 11 developing countries. The countries most highly dependent on nuclear power are clustered in Europe (Figure 9-41), where it supplies 80 percent of all electricity in France and more than 50 percent in Belgium, Slovakia, and Ukraine.

Dependency on nuclear power varies widely among U.S. states (Figure 9-42). Nuclear power accounts for more than 70 percent of electricity in Vermont and more than one-half in Connecticut, New Jersey, and South Carolina. At the other extreme, 20 states and the District of Columbia have no nuclear power plants. Nuclear power presents serious challenges, as described in the following sections.

POTENTIAL ACCIDENTS. A nuclear power plant produces electricity from energy released by splitting uranium atoms in a controlled environment, a process called **fission**. One product of all nuclear reactions is **radioactive waste**, certain types of which are lethal to people exposed to it. Elaborate safety precautions are taken to prevent the leaking of nuclear fuel from a power plant.

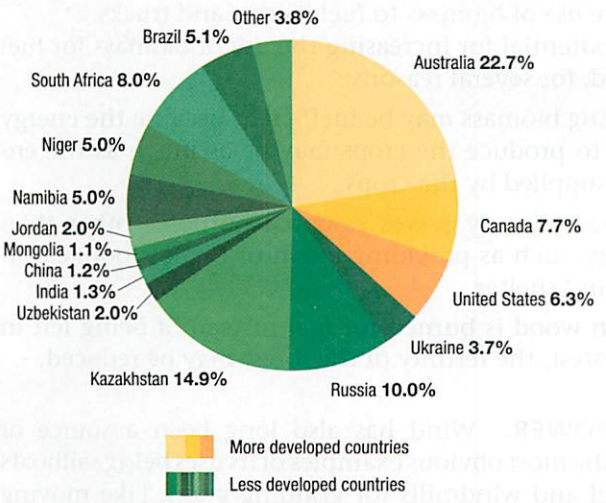
Nuclear power plants cannot explode, like a nuclear bomb, because the quantities of uranium are too small and cannot be brought together fast enough. However, it is possible to have a runaway reaction, which overheats the reactor, causing a meltdown, possible steam explosions, and scattering of radioactive material into the atmosphere. This happened in 1986 at Chernobyl, then in the Soviet Union and now in the north of Ukraine, near the Belarus border. The accident caused 56 deaths due to exposure to high radiation doses and an estimated 4,000 cancer-related deaths to people who lived near the plant.

Following an earthquake and tsunami in 2011, three of the six reactors at Japan's Fukushima Daiichi nuclear power plant experienced full meltdown, resulting in release of radioactive materials. Three workers died; the death toll among nearby residents exposed to high levels of radioactivity won't be known for years.

RADIOACTIVE WASTE. The waste from nuclear fission is highly radioactive and lethal, and it remains so for many years. Plutonium for making nuclear weapons can be harvested from this waste. Pipes, concrete, and water near the fissioning fuel also become "hot" with radioactivity. No one has yet devised permanent storage for radioactive waste. The waste cannot be burned or chemically treated, and it must be isolated for several thousand years until it loses its radioactivity. Spent fuel in the United States is stored "temporarily" in cooling tanks at nuclear power plants, but these tanks are nearly full. The United States is Earth's third-largest country in land area, yet it has failed to find a suitable underground storage site because of worry about groundwater contamination. In 2002, the U.S. Department of Energy approved a plan to store the waste in Nevada's Yucca Mountains. But soon after taking office in 2009, the Obama administration reversed the decision and halted construction on the nearly complete repository.

BOMB MATERIAL. Nuclear power has been used in warfare twice, in August 1945, when the United States dropped atomic bombs on Hiroshima and Nagasaki, Japan, ending World War II. No government has dared to use these bombs in a war since then because leaders recognize that a full-scale nuclear conflict could terminate human civilization.

The United States and Russia (previously the Soviet Union) each have several thousand nuclear weapons. China, France, and the United Kingdom have several hundred nuclear weapons each, India and Pakistan several dozen each, and North Korea a handful. Israel is suspected of possessing nuclear weapons but has not admitted to it, and Iran has been developing the capability. Other countries have initiated nuclear programs over the years but have not advanced to the weapons stage. The diffusion of nuclear programs to countries sympathetic to terrorists has been particularly worrying to the rest of the world and has been a major factor in long-time tensions between Iran and other countries that do not want Iran to gain the capability of building a nuclear weapon.



▲ FIGURE 9-43 **WORLD URANIUM RESERVES**
Australia, Kazakhstan, and Russia have the most uranium reserves.

Pause and Reflect 9.3.5

Iran has claimed that it is interested in nuclear power for peaceful uses. Review the maps and charts of fossil fuel production and proven reserves on the previous two spreads. Does Iran appear to have other resources for generating electricity?

LIMITED URANIUM RESERVES. Like fossil fuels, uranium is a nonrenewable resource. Proven uranium reserves will last about 124 years at current rates of use. And they are not distributed uniformly around the world: Australia has 23 percent of the world's proven uranium reserves, Kazakhstan 15 percent, and Russia 10 percent (Figure 9-43). The chemical composition of natural uranium further aggravates the scarcity problem. Uranium ore naturally contains only 0.7 percent U-235; a greater concentration is needed for power generation.

A **breeder reactor** turns uranium into a renewable resource by generating plutonium, also a nuclear fuel. However, plutonium is more lethal than uranium and could cause more deaths and injuries in an accident. It is also easier to fashion into a bomb. Because of these risks, few breeder reactors have been built, and none are in the United States.

HIGH COST. Nuclear power plants cost several billion dollars to build, primarily because of the elaborate safety measures required. Without double and triple backup systems at nuclear power plants, nuclear energy would be too dangerous to use. Uranium is mined in one place, refined in another, and used in still another. As with coal, mining uranium can pollute land and water and damage miners' health. The complexities of safe transportation add to the cost. As a result, generating electricity from nuclear plants is much more expensive than from coal-burning plants. The future of nuclear power has been seriously hurt by the high costs associated with reducing risks.

RENEWABLE ENERGY

Learning Outcome 9.3.6

Identify challenges to increasing the use of alternative energy sources.

By a wide margin, hydroelectric power is currently the leading source of renewable energy for sustainable development in both developed and developing regions. Biomass and wind power have some usages, and geothermal and solar trail even further in current usage.

HYDROELECTRIC POWER. Generating electricity from the movement of water is called **hydroelectric power**. Water has been a source of mechanical power since before recorded history. It was used to turn water wheels, and the rotational motion was used to grind grain, saw timber, pump water, and operate machines. Hydroelectric is now the world's second-most-popular source of electricity, after coal. Worldwide generation of hydroelectric power is approximately 30 quad BTU, compared to 150 quad BTU for coal.

Two-thirds of the world's hydroelectric power is generated in developing countries and one-third in developed countries. A number of developing countries depend on hydroelectric power for most of their electricity (Figure 9-44). The most populous country to depend primarily on hydroelectric power is Brazil. Overall, Brazil has made considerable progress towards sustainable development by generating approximately 85 percent of its electricity from renewable energy sources. Among developed countries, Canada gets two-thirds of its electricity from hydroelectric power; although the United States is the fourth-leading producer of hydroelectric power, it obtains only 8 percent of its electricity from that source. And this percentage may decline because few acceptable sites to build new dams remain.

▼ **FIGURE 9-44 ELECTRICITY FROM HYDROELECTRIC POWER** Hydroelectricity provides a large percentage of electricity in a number of developing countries, especially in Latin America and sub-Saharan Africa. The Itaipú hydroelectric dam is on the Paraná River in Brazil.

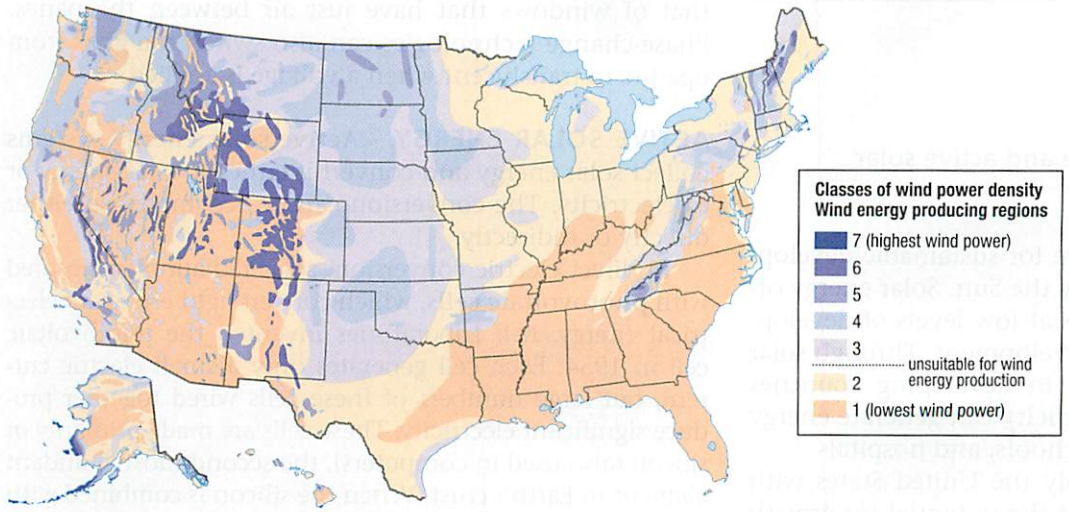
▲ **FIGURE 9-45 BIOMASS FUEL IN BRAZIL** Ethanol is produced from sugarcane in Brazil. This ethanol-producing plant is in Piracicaba.

BIOMASS. **Biomass fuel** is fuel derived from plant material and animal waste. Biomass energy sources include wood and crops. When carefully harvested in forests, wood is a renewable resource that can be used to generate electricity and heat. The waste from processing wood, such as for building construction and demolition, is also available. And crops such as sugarcane, corn, and soybeans can be processed into motor-vehicle fuels. Worldwide production of biomass fuel is approximately 3 quad BTUs, including one-third each in North America, Europe, and developing regions (Figure 9-45). Brazil in particular makes extensive use of biomass to fuel its cars and trucks.

The potential for increasing the use of biomass for fuel is limited, for several reasons:

- Burning biomass may be inefficient because the energy used to produce the crops may be as much as the energy supplied by the crops.
- Biomass already serves essential purposes other than energy, such as providing much of Earth's food, clothing, and shelter.
- When wood is burned for fuel instead of being left in the forest, the fertility of the forest may be reduced.

WIND POWER. Wind has also long been a source of energy, the most obvious examples of its uses being sailboats for travel and windmills for grinding grain. Like moving water turning a water wheel, moving air can turn a turbine.



◀ **FIGURE 9-46 WIND POWER** Winds are especially strong enough to support generation of power in the U.S. Plains states.

The benefits of wind-generated power seem irresistible. Construction of a windmill modifies the environment much less severely than construction of a dam across a river. And wind power has greater potential for increased use because only a small portion of the potential resource has been harnessed. However, wind power has divided the environmental community. Some oppose construction of windmills because they can be noisy and lethal for birds and bats. They can also constitute a visual blight when constructed on mountaintops or offshore in places of outstanding beauty.

Wind usage is similar to the pattern for biomass: Worldwide production is 3 quad BTUs, divided one-third each among North America, Europe, and developing regions. Hundreds of wind "farms" consisting of dozens of windmills each have been constructed across the United States; one-third of the country is considered windy enough to make wind power economically feasible (Figure 9-46), especially North Dakota, Texas, Kansas, South Dakota, and Montana. Twenty percent of Denmark's electricity is being generated through wind power. Wind power has been used only to a limited extent in developing countries. A significant obstacle is the cost of constructing the wind turbines.

Pause and Reflect 9.3.6

Chicago is nicknamed "the Windy City." Based on Figure 9-46, does the Chicago area appear to be a good location for wind power?

GEOTHERMAL ENERGY. Natural nuclear reactions make Earth's interior hot. Toward the surface, in volcanic areas, this heat is especially pronounced. The hot rocks can encounter groundwater, producing heated water or steam that can be tapped by wells. Energy from this hot water or steam is called **geothermal energy**.

Harnessing geothermal energy is most feasible at sites along Earth's surface where crustal plates meet, which are also the sites of many earthquakes and volcanoes. Geothermal energy is being tapped in several locations, including California, Italy, New Zealand, and Japan, and other plate boundary sites are being explored. Iceland and Indonesia make extensive use of geothermal energy. Ironically, in Iceland, an island named for its glaciers, nearly all homes and businesses in the capital of Reykjavik are heated with geothermal steam (Figure 9-47). Worldwide production is less than 1 quad BTU, divided about evenly between developed and developing regions.

NUCLEAR FUSION. Some nuclear power issues could be addressed through nuclear **fusion**, which is the fusing of hydrogen atoms to form helium. Fusion releases spectacular amounts of energy: A gnat-sized amount of hydrogen releases the energy of thousands of tons of coal. But fusion can occur only at very high temperatures (millions of degrees). Such high temperatures have been briefly achieved in hydrogen bomb tests but not on a sustained basis in a power-plant reactor, given present technology. Sources such as fusion are not yet practical, so do not appear in statistics of current energy production.

▼ **FIGURE 9-47 GEOTHERMAL** Geothermal plant near Krafla, Iceland.

SOLAR ENERGY

Learning Outcome 9.3.7

Compare and contrast passive and active solar energy.

The ultimate renewable resource for sustainable development is solar energy supplied by the Sun. Solar energy offers the possibility for countries at low levels of development to promote sustainable development. Through solar energy, people and businesses in developing countries currently unable to obtain electricity can generate energy needed to operate businesses, schools, and hospitals.

Solar sources currently supply the United States with only 1 percent of electricity, but the potential for growth is limitless. The Sun's remaining life is estimated at 5 billion years, and humans appear to be incapable of destroying or depleting that resource. The Sun's energy is free and ubiquitous and cannot be exclusively owned, bought, or sold by any particular individual or enterprise. Utilizing the Sun as a resource does not damage the environment or cause pollution, as does the extraction and burning of nonrenewable fossil fuels.

PASSIVE SOLAR ENERGY. Solar energy is harnessed through either passive or active means. **Passive solar energy systems** capture energy without using special devices. These systems use south-facing windows and dark surfaces to heat and light buildings on sunny days. The Sun's rays penetrate the windows and are converted to heat. Humans act as passive solar energy collectors when they are warmed by sunlight. And since dark objects absorb more energy than light ones, wearing dark clothing warms a person exposed to sunlight even more.

Reliance on passive solar energy increased during the nineteenth century when construction innovations first permitted the hanging of massive glass "curtains" on a thin steel frame. Greenhouses enabled people to grow and view vegetation that required more warmth to flourish than the local climate permitted. Early skyscrapers made effective use of passive solar energy. During World War II when fossil fuels were rationed, consumers looked for alternative energy sources. A major glass manufacturer, Libbey-Owens-Ford Glass Co., responded by publishing a book in 1947 entitled *Your Solar House*. But with electricity and petroleum cheap and abundant after World War II and through most of the twentieth century, passive solar energy rarely played a major role in construction of homes and commercial buildings.

In recent years, building construction and remodeling have made more use of passive solar energy through advances in glass technology. Double- and triple-pane windows have higher insulating values, and low-E (low emissivity) glass can be coated to let heat in but not out. Window panes made with this glass are filled with argon or other gases that increase their insulating values beyond that of windows that have just air between the panes. Phase-change technologies can also switch the glass from opaque to translucent when a voltage is applied.

ACTIVE SOLAR ENERGY. **Active solar energy systems** collect solar energy and convert it either to heat energy or to electricity. The conversion can be accomplished either directly or indirectly.

In direct electric conversion, solar radiation is captured with **photovoltaic cells**, which convert light energy to electrical energy. Bell Laboratories invented the photovoltaic cell in 1954. Each cell generates only a small electric current, but large numbers of these cells wired together produce significant electricity. These cells are made primarily of silicon (also used in computers), the second most abundant element in Earth's crust. When the silicon is combined with one or more other materials, it exhibits distinctive electrical properties in the presence of sunlight, known as the photovoltaic effect. Electrons excited by the light move through the silicon, producing direct current (DC) electricity.

In indirect electric conversion, solar radiation is first converted to heat and then to electricity. The Sun's rays are concentrated by reflectors onto a pipe filled with synthetic oil. The heat from the oil-filled pipe generates steam to run turbines. In heat conversion, solar radiation is concentrated with large reflectors and lenses to heat water or rocks. These store the energy for use at night and on cloudy days. A place that receives relatively little sunlight can use solar energy by using more reflectors and lenses and larger storage containers.

Pause and Reflect 9.3.7

Why are people warned not to leave a dog or child unattended in a parked car during the summer?

GENERATING ELECTRICITY THROUGH SOLAR POWER. Solar power can be produced at a central station and distributed by an electric company, as coal- and nuclear-generated electricity are now supplied. However, with coal still relatively cheap and investment in nuclear facilities already substantial, public and private utility companies have had little interest in solar technology.

In developed countries, solar-generated electricity is used in spacecraft, light-powered calculators, and at remote sites where conventional power is unavailable, such as California's Mojave Desert. Solar energy is used primarily as a substitute for electricity in heating water. Rooftop devices collect, heat, and store water for apartment buildings in Israel and Japan and individual homes in the United States (Figure 9-48). The initial cost of installing a solar water heater is higher than hooking into the central system but may be justified if an individual plans to stay in the same house for a long time.

Electricity was popular in early motor vehicles. Of the 4,000 cars sold in the United States in 1900, 38 percent were powered by electricity, 40 percent by steam, and only

▲ FIGURE 9-48 **SOLAR PANELS** Solar panels installed on apartment rooftops in the Old City of Jerusalem are used to heat water, which is stored in the adjacent tanks. The domes are the Church of the Holy Sepulchre, built at the site where Jesus is thought to have been crucified, buried, and resurrected (see Chapter 6).

22 percent by gasoline. The electric car was especially popular in 1900 in large cities of the Northeast, such as New York and Philadelphia, where their relative quietness and cleanliness made them popular as taxicabs. Women also preferred electric cars because they were easier to start than gasoline- or steam-powered ones.

The main shortcomings of the electric car in the early 1900s remain unchanged a century later. Compared to gasoline power, the electric-powered vehicle has a more limited range and costs more to operate. Recharging the battery can take several hours. To address these issues, carmakers offer a variety of vehicles that combine electric and gasoline power. Hybrid vehicles conserve gasoline by running on electricity at low speeds. Other vehicles operate exclusively on battery-powered electricity and use the gasoline engine to recharge the battery (see Chapter 13).

▲ FIGURE 9-49 **SOLAR ENERGY IN DEVELOPING COUNTRIES** Solar panels are generating electricity for this family's house in Rumbek, South Sudan.

In developing countries, the largest and fastest-growing market for photovoltaic cells includes the 2 billion people who lack electricity, especially residents of remote villages. For example, in sub-Saharan Africa, more homes have been electrified in recent years using photovoltaic cells than by hooking up to the central power grid (Figure 9-49). In Morocco, solar panels are sold in bazaars and open markets, next to carpets and tinware.

Solar energy currently accounts for only 0.3 quad BTU worldwide. The cost of cells must drop and their efficiency must improve for solar power to expand rapidly, with or without government support. Solar energy will become more attractive as other energy sources become more expensive. A bright future for solar energy is indicated by the fact that petroleum companies now own the major U.S. manufacturers of photovoltaic cells.

CHECK-IN: KEY ISSUE 3

Why Are Energy Resources Important for Development?

- ✓ **Energy is supplied primarily by three fossil fuels: coal, petroleum, and natural gas.**
- ✓ **The three fossil fuels are nonrenewable, and production and reserves of these fuels are not distributed uniformly across Earth.**
- ✓ **Alternative energy sources include solar, nuclear, biomass, hydroelectric, geothermal, and fusion.**