



## Petroleum

**Petroleum** is a valuable substance, used as a fuel and as a raw material, that comes from rocks far beneath the ground. The word *petroleum* comes from Greek words meaning *rock oil*. Petroleum comes in two forms—a liquid and a gas. Liquid petroleum is commonly called *crude oil*. Gaseous petroleum is often referred to as *natural gas*. The remainder of this article uses *petroleum* to mean both crude oil and natural gas. For more information on natural gas, see Gas.

Petroleum consists of a mixture of different chemicals that can be separated into a number of useful substances. Many petroleum products are used as fuels. Gasoline supplies fuel for transportation, and fuel oil burns to generate electric power in power plants. Natural gas heats houses and other buildings and provides fuel for electric generators. Other petroleum products serve as raw materials in manufacturing. Some serve as lubricants, while others are a basic component in the making of plastics.

Most geologists believe petroleum developed from the remains of plants and animals that died long ago. These remains became buried deep below the ground. There, heat and pressure transformed them into petroleum. Over time, this petroleum moved through rock to the areas where it is found today. Petroleum deposits also moved as Earth's surface shifted.

Geologists use their knowledge of how petroleum forms and *migrates* (moves through rock) to find underground petroleum deposits. They also search for petroleum using special equipment, including magnetic sensors, devices that vibrate the ground, and instruments that measure tiny variations in Earth's gravity.

Engineers and drilling crews use special equipment to drill a well to a petroleum deposit. The well serves as a passageway through which petroleum flows to the surface. From the well, pipelines and ships transport the petroleum to a *refinery*, a vast area of towers, tanks, pipes, pumps, and valves where petroleum is converted into various products.

Petroleum supplies over half of the world's energy. All countries use petroleum, and about 110 countries produce it. Most of the world's richest countries, including the United States, Japan, and several nations in Western Europe, use much more petroleum than they produce. On the other hand, a small number of relatively poor countries, many of them in the Middle East, produce much more petroleum than they consume. The need of wealthy countries to import large amounts of petroleum has led to global economic and political problems and even to war.

The widespread use of petroleum has given rise to a number of environmental problems. During the production, transportation, and use of petroleum, some of it spills or seeps onto the land and into the water. The burning of petroleum produces waste particles and gases



that pollute the air. Burning petroleum produces carbon dioxide (CO<sub>2</sub>) gas, which many scientists believe is causing Earth's surface to become warmer.

People have used petroleum for thousands of years. Petroleum did not become a major energy source, however, until the mid-1800's. At that time, the invention of the kerosene lamp and, later, the automobile created an enormous demand for kerosene and gasoline—two fuels derived from petroleum. Today, the petroleum industry is one of the largest in the world.

Earth has only a limited supply of petroleum. As more and more is used, what remains will become increasingly expensive to *produce* (remove from the ground). Improved production methods, increases in fuel efficiency, and conservation may allow petroleum to remain the world's primary source of energy for some time. Eventually, however, other energy sources will have to replace petroleum.

## The composition of petroleum

Petroleum consists mainly of a mixture of molecules called *hydrocarbons*. Hydrocarbons are combinations of two chemical elements, carbon (C) and hydrogen (H). Carbon atoms combine readily with one another, forming molecules shaped like chains, branches, and rings. Hydrogen atoms attach to the carbon atoms in these structures. The simplest hydrocarbon, called *methane* (CH<sub>4</sub>), consists of four hydrogen atoms attached to a single carbon atom. Complex hydrocarbons can have 30 or more carbon atoms. Some petroleum deposits include hundreds of different kinds of hydrocarbons. See Hydrocarbon.

Different hydrocarbons in a petroleum deposit may exist as gases, liquids, or solids, depending on the temperature and pressure inside the deposit. Small molecules, such as methane, tend to exist as gases. These gases can be found at the top of a petroleum deposit or may be dissolved in liquid. Hydrocarbons with molecules that contain five or more carbon atoms are often found as liquids. Hydrocarbons with extremely large molecules tend to exist as solids.

Each petroleum deposit contains a unique mixture of hydrocarbons. This mixture determines the *viscosity* (resistance to flow) of the deposit's crude oil. Some crude oils, called *light crudes*, have a relatively low viscosity—that is, they flow rather easily. Light crudes consist mainly of smaller hydrocarbon molecules and contain large amounts of dissolved gases. Crude oils that contain a high proportion of large hydrocarbon molecules are called *heavy crudes*. Heavy crudes have a relatively high viscosity. Light crudes can be produced, transported, and refined more cheaply and more easily than heavy crudes. Some heavy crudes are too thick to be produced at a profit.

In addition to hydrocarbons, all crude oils contain impurities, such as metallic compounds and sulfur. These impurities can make up as much as 5 percent of the weight of some crude oils.



## Uses of petroleum

Petroleum has a greater variety of uses than perhaps any other substance in the world. Mixtures of different hydrocarbons give special characteristics to various *fractions* (parts) of petroleum. People use some fractions of petroleum, such as gasoline and kerosene, in their natural state. Other fractions must be further processed or combined with different substances before they can be used. Petroleum companies process most petroleum into gasoline, heating oil, and other fuels. The rest is converted chiefly into industrial raw materials and lubricants.

**Petroleum as a fuel.** Petroleum fuels ignite and burn readily and produce a great amount of heat in relation to their weight. They are also easier to handle, store, and transport than such other fuels as coal and wood. Petroleum is the source of nearly all the fuels used for transportation and of many fuels used to produce heat and electric power.

Fuels for transportation include gasoline, diesel fuel, and jet fuel. Most light motor vehicles and all piston-engine airplanes use gasoline. Nearly all trains, ships, buses, and large trucks use diesel fuel. Diesel fuel requires less refining and is cheaper than gasoline. Jet airplanes burn jet fuel, which is either pure kerosene or a mixture of gasoline and kerosene.

Other petroleum fuels are used to generate heat and electric power. Such fuels include *distillate oils* and *residual oils*. Distillate oils are lighter oils, most of which are used to heat houses and small business places. Residual oils are heavier, thicker oils. They provide power for electric utilities, factories, and large ships. Residual oils are also used to heat large buildings.

Where access to a natural gas pipeline is available, many homes use natural gas for cooking and heating. People who do not have access to a pipeline, including many people who live on farms or in mobile homes, often use *liquefied petroleum gas* (LPG) for heating and cooking. LPG is a gas formed during petroleum refining that has been compressed until it forms a liquid. LPG is used in industry for cutting and welding metals and on farms for operating some kinds of equipment.

**Petroleum as a raw material.** Other petroleum fractions serve as raw materials in manufacturing. Many of these fractions are converted into chemicals called *petrochemicals*. Petrochemicals serve as a basic ingredient in the manufacture of *polymers*. Polymers are large molecules formed by the chemical linking of many smaller molecules into a long chain. Manufacturers use polymers to create plastics and other synthetic fibers for a wide variety of products, including food packaging, sewing thread, and computer casings and parts. Petrochemicals also form an ingredient in many cosmetics, detergents, drugs, fertilizers, and insecticides, and in hundreds of other products.

By-products of petroleum refining also serve as raw materials in certain industries. These by-products include asphalt, the chief roadbuilding material; and wax, an essential ingredient in such products as candles and furniture polish.



**Other uses.** Factories convert other petroleum fractions into lubricants or industrial oils. Lubricants reduce friction between the moving parts of equipment. They range from the thin, clear oil used in scientific instruments to the heavy grease applied to aircraft landing gear. Specialized industrial oils include cutting oils and electrical oils, which are used in manufacturing.

## How petroleum deposits form

Petroleum developed from the remains of tiny organisms that died hundreds of millions of years ago. Those organisms once lived in the waters of river deltas and along coastlines. As they died, their remains settled to the sea floor and became trapped in *sediment* (particles of sand, mud, clay, and other materials). The remains consisted mostly of water molecules and organic materials rich in carbon and hydrogen. Over time, new layers of sediment piled up. As the sediments containing the remains became buried deeper and deeper, they were exposed to more intense heat and pressure. These forces compressed the sediment into rock. At the same time, chemical reactions changed the organic material into a waxy substance known as *kerogen*. Further heating caused the kerogen to separate into crude oil and natural gas.

Most petroleum did not remain where it was formed. It migrated through rock and was transported as Earth's outer layers shifted.

**Migration** occurred as petroleum traveled through *porous* rock. Porous rock contains tiny holes, or *pores*, that allow fluids to flow into and through the rock. Petroleum flowed differently into different kinds of rock. It flowed most easily through porous rocks called *sandstones* and *carbonates*. These rocks are called *permeable* rocks because they have interconnected pores that allowed petroleum to pass through them.

Petroleum migrated because water was present in the porous rock where petroleum formed. Water, which is denser than most petroleum, flowed slowly downward through the rock. The water displaced petroleum and forced it to flow upward. Natural gas is less dense than crude oil. Therefore, in deposits where petroleum included undissolved gas, the gas migrated even farther upward. Eventually, the crude oil settled on top of the water. If gas was present, it settled on top of the oil.

As petroleum migrated upward, it tended to flow into areas of more permeable rock. Thus it may have moved several miles or kilometers from where it originally formed. Eventually, the petroleum migrated to a place where it was surrounded by rock with few or no pores. This rock, called *impermeable rock*, prevented the petroleum from moving upward. Such an area is called a *petroleum trap*. The petroleum collected below the trap in an area of porous rock is called a *petroleum reservoir*.

The most common kinds of petroleum traps are *anticlines*, *faults*, *stratigraphic traps*, and *salt domes*. An anticline is an archlike formation of rock under which petroleum may collect. A fault is a fracture in Earth's rocky outer shell. Rock can shift along a fault, moving an impermeable layer of rock next to a permeable one that contains oil. Most stratigraphic traps



consist of layers of impermeable rock that surround oilbearing rocks. In a salt dome, a cylinder- or cone-shaped formation of salt pushes up through sedimentary rocks, causing the rocks to arch and fracture in its path. Petroleum may accumulate above or along the sides of such a formation.

**Shifting of Earth's surface** changed the position of the ancient deltas and coastlines where petroleum formed. Earth's surface is made up of about 30 huge, rigid slabs called tectonic plates. The plates slide around over a layer of rock that is so hot that it flows, even though it remains solid. The continents are embedded in the tops of plates, so as those plates move, they carry the continents along with them. See Plate tectonics.

The shifting of the plates moved some of the deltas and coastlines where petroleum had formed. Some of these areas moved inland. Others sank into much deeper waters, in some cases to depths of more than 2 miles (3.2 kilometers). In some places, a single deposit of petroleum appears to have split where two plates broke apart and drifted away from each other, carrying the petroleum with them.

## Finding petroleum

Until the 1990's, drilling for petroleum was a major financial risk. A success rate of 20 percent—finding 2 producing wells for every 10 wells drilled—was considered normal. Since then, however, scientists and engineers have developed technology that has raised this success rate to about 70 percent. Prospectors are able to conduct geological studies to locate areas where petroleum will likely be found. Geophysical studies help prospectors confirm the presence of petroleum and learn more about the deposit.

**Geological studies.** Petroleum geologists study rock formations on and below Earth's surface to determine where petroleum might be found. They may begin by selecting an area that seems favorable to the formation of petroleum. Geologists then make a detailed map of the surface features of the area. They may use photographs taken from airplanes and satellites in addition to their ground-level observations. The geologists study the map for signs of possible oil traps. For example, the appearance of a low bulge on an otherwise flat surface may indicate the presence of a salt dome, a common petroleum trap.

If the site looks promising, geologists may use a drill to obtain *cores*, cylindrical samples of the underground layers of rock. The geologists analyze the cores for chemical composition, structure, and other factors that relate to the formation of petroleum.

Geologists may also study *well logs*. A well log is a record of the rock formations encountered during the drilling of a well. Well logs describe such characteristics as the radioactivity, density, and fluid content of the rocks. Geologists use well logs from a certain area to estimate the location and size of other possible petroleum deposits in the same area.

**Geophysical studies** help prospectors confirm the presence of petroleum in an area or determine new areas for petroleum exploration. Scientists called *geophysicists* search for



petroleum by measuring gravity and magnetism. They also conduct *seismic studies*, studies of vibrations in the ground.

**Gravity measurements** help prospectors locate porous rocks deep below the ground. The pull of gravity is slightly stronger at places on Earth's surface where underground rocks are more dense. Likewise, the pull of gravity is slightly weaker where underground rocks are less dense. Porous rocks are much less dense than nonporous rocks. Also, petroleum is generally less dense than water, so porous rocks that contain petroleum are usually less dense than those that contain water. Geophysicists can locate low-density rocks that may contain petroleum by finding areas where gravity's pull is relatively weak.

Geophysicists measure Earth's gravity using a device called a *gravity meter* or *gravimetergruh VIHM uh tuhr*. The meter consists of a weight hanging from a very sensitive spring. Tiny changes in Earth's gravity cause the spring to lengthen or shorten. The meter measures the length of the spring to determine the pull of gravity.

**Magnetic measurements** help scientists locate petroleum deposits that were transported as Earth's crust shifted. Each rock formation has its own *magnetic field*, an invisible region of magnetic force that is *aligned* (lined up) in a certain direction. The strength and alignment of the magnetic field depends on where the rock originally formed. By measuring the rock's magnetic field, scientists can determine where a formation originated. For example, magnetic analysis might indicate that a particular formation was an ancient river delta or ocean coast when the rock formed. Such a formation might contain petroleum.

Geophysicists measure the magnetic field using a device called a *magnetometerMAG nuh TOM uh tuhr*. The magnetometer measures both the *declination* (compass direction) and the *inclination* (up-and-down direction) of the magnetic field. Scientists can take these measurements from the air or on the surface.

**Seismic studies** help scientists locate deposits of petroleum below the ground. During a seismic study, scientists use special equipment to generate a *seismic event*, a miniature earthquake in which waves of vibration travel downward through the ground. These waves travel to different layers of underground rock and bounce back. By studying the waves that bounce back, scientists can determine the depth and density of different layers of rock. This allows them to locate potential petroleum traps. Sensitive measurements can even reveal direct evidence of petroleum trapped in the rock. Seismic studies require a great amount of work and special equipment. For this reason, petroleum companies often limit such studies to areas of fewer than 40 square miles (100 square kilometers).

In the early days of seismic studies, petroleum prospectors used several thousand pounds of explosives to create a seismic event. Today, special *thumper trucks* create the vibrations by hammering the ground. The reflected waves are recorded by a group of sensors called *geophones*.

To search for petroleum deposits beneath the ocean floor, a ship equipped with devices called *air guns* shoots highly pressurized air into the water. The air generates a wave of energy that travels to the ocean floor. When the wave strikes the floor, it creates a seismic



event, sending waves of vibration traveling downward through the rock. Sensors called *hydrophones* record the vibrations reflected by different layers.

Geophones and hydrophones transmit their data to a computer. The computer can display the data mathematically or produce an image of the underground rock formations. Data from a single seismic event can generate a two-dimensional view called a *cross section* of the rock layers beneath the surface. Often, the truck or boat will move, generating several seismic events as the geophones or hydrophones follow it. This generates a series of cross sections which the computer can combine to form a three-dimensional model of rock formations beneath the ground.

Seismic studies have revolutionized petroleum exploration. Many petroleum engineers believe advances in seismic exploration have brought about much of the improvement in the success rate of well drilling. Three-dimensional seismic models have reduced the uncertainty involved in drilling a new well. They have also enabled prospectors to identify previously overlooked deposits.

Seismic models have also helped petroleum companies produce petroleum more efficiently. Engineers and geologists can use seismic models to determine the best place to drill into a deposit. In this way, seismic models reduce the number of wells needed and greatly speed the process of producing petroleum. These advances have made petroleum production faster and cheaper, allowing companies to produce petroleum from deposits that were once considered too small to be profitably mined.

Petroleum companies can also conduct seismic studies of a deposit as petroleum is extracted. Geologists use this information to monitor the petroleum remaining in a deposit. This technique has allowed more petroleum to be extracted from reservoirs where production had ceased.

## Drilling for petroleum

Once prospectors have located a potential petroleum deposit, a drilling crew must drill a well to the suspected reservoir. New wells are called *wildcat wells*, reflecting the uncertainty of finding petroleum. Drilling crews use a giant drill called a *rotary drilling rig* to bore a hole down to the petroleum. They also can drill a well using special equipment that turns at an angle or even travels sideways, a technique called *directional drilling*. Drilling a well allows geologists to test and evaluate a petroleum deposit.

**A rotary drilling rig** consists of a powerful drill and the machines and structures that allow it to operate. The drill is mounted on a tall structure called a *derrick*. The derrick supports the *drill pipe*, a length of pipe that descends into the well as it is drilled. The drill pipe consists of smaller sections of pipe attached end to end. A large drill bit is attached to the bottom of the drill pipe. A turntable on the floor of the derrick rotates the drill pipe, causing the bit to grind through soil and rock. As the bit drills deeper, the drill pipe is lowered into the ground. When the drill pipe cannot be lowered any farther, workers attach another length of pipe to the top



of the drill pipe and continue drilling.

Workers raise and lower the drill pipe using a hoisting mechanism called the *draw works*. The draw works operates somewhat like a fishing rod and reel. Steel cable is unwound from a motorized wheel called the *hoisting drum*. The cable is then threaded through two *blocks* (sets of pulleys)—the *crown block*, at the top of the rig, and the *traveling block*, which hangs inside the derrick. The workers attach the upper end of the drill pipe to the traveling block with a giant hook. They can then lower the pipe into the hole or lift it out by turning the hoisting drum.

Workers use a special fluid to lubricate the drill bit. This fluid, called *mud*, is a complex artificial mixture with many ingredients. Workers pump mud down through the drill pipe. At the bottom of the pipe, the mud flows out and lubricates the drill bit. The mixture then flows up around the outside of the drill pipe and out of the well. The mud carries away the bits of rock that the drill has broken loose, keeping the well free from debris.

Workers continue to add length to the drill pipe until the well reaches the petroleum reservoir. Working in this manner, drilling crews have drilled experimental wells more than 9 miles (14 kilometers) deep. Petroleum wells often measure 5,000 to 20,000 feet (1,500 to 6,100 meters) deep.

Special drilling rigs can be used to drill for oil beneath the ocean floor. These rigs may be mounted on a stable platform, on a floating platform, or on a special boat called a *drillship*. Drillship crews use small computer-controlled propellers called *thrusters* to keep the ship steady over the well.

**Directional drilling.** Most wells are drilled straight down. Some drilling crews, however, use directional drilling equipment to drill wells that turn to one side as they penetrate the rock. These wells may even turn so much that the drill bit moves horizontally. Directional drilling requires special drills. These drills are powered by the pressure of mud, water, or air flowing through the drill bit.

Directional drilling can help a well reach deeper into the petroleum reservoir. This exposes more of the well's length to reservoir rock, speeding the rate at which the well produces petroleum. Directional drilling also enables petroleum companies to drill wells that branch off from a single vertical well. This allows several wells to be drilled without moving the drilling rig.

Some directionally drilled wells are *multilateral wells*. These wells have branches that leave the main well at about the same level. Other directionally drilled wells are *multilevel wells*. Branches in these wells leave the main well at two or more levels. Some extremely long horizontal wells travel sideways for several miles or kilometers. Some complex wells have several branches extending hundreds of feet or meters from the main shaft.

Special tools and instruments enable crews to take measurements while drilling and to track the bit as it advances. As drilling proceeds, the crew makes continuous measurements and compares them with knowledge obtained from seismic measurements and information from



previously drilled wells. The crew uses this information to steer the drill. This technique, known as *geosteering*, allows the crew to pinpoint exact locations inside a petroleum reservoir.

**Reservoir evaluation.** Once a well has been drilled, scientists test and evaluate the petroleum deposit. Using data from seismic studies, they calculate the volume of natural gas, crude oil, and water in the reservoir. They analyze cores, well logs, and *mud logs* to find out how porous and permeable the reservoir rock is. Mud logs are records of different types of rock and other substances carried to the surface by drilling mud. Scientists test samples of petroleum from the new well to determine its viscosity and chemical composition. They also measure the amount of pressure the petroleum is under.

Evaluation allows scientists and engineers to predict the well's *production rate*—that is, how rapidly the well can produce petroleum. Testing the petroleum can help determine how difficult it will be to extract and refine. Petroleum companies use this information to determine if the petroleum can be produced at a profit.

## Producing petroleum

If testing indicates that the petroleum in a deposit can be profitably extracted, workers prepare the well for production. This process is called *completing* the well. Once the well has been completed, it can begin producing petroleum.

**Completing the well.** Wells are completed as soon as possible because a well that is left open can quickly develop problems. A well in brittle rock might fill up with debris or even collapse. An open well shaft can allow other fluids to mix with the petroleum, complicating the extraction and refining process. An open well can also allow petroleum to leak into *aquifers* (reservoirs of water in the rock), contaminating the local water supply. Open wells can decrease the pressure inside a petroleum reservoir, making the petroleum difficult or impossible to extract.

Workers begin by lining the well with metal pipes called *casing*. They then fill the space around the casing with concrete to seal different rock formations from one another. When the concrete has hardened, workers lower a device called a *perforator* to the bottom of the well. The perforator uses explosives to blast holes in the casing that will allow petroleum to flow into the well. Workers then lower a thinner pipe called *tubing* that will carry the petroleum to the surface. They remove the drilling rig and place a device called a *Christmas tree* over the well. A Christmas tree is a series of pipes and valves that controls the flow of petroleum.

**Stimulating production.** The oil in the reservoir is under pressure. This pressure drives petroleum into the well. However, the drilling process often damages the reservoir rock near the well, decreasing its permeability. This can slow the flow of petroleum or even prevent it from entering the well. Drillers use *stimulation* techniques to restore or increase the flow of petroleum.



Some stimulation techniques use chemicals. Engineers can flush solutions of hydrochloric acid and hydrofluoric acid down the well to dissolve particles of drilling mud and natural clay that tend to accumulate around the well. They may use a hydrocarbon called *toluene* and other organic solvents to remove solid fractions of petroleum, such as *paraffins* (waxes) and *asphaltenes* (hard, brittle particles of asphalt), which can also gum up the rock near the well.

Another stimulation technique, called *hydraulic fracturing* or *fracking* for short, creates a crack in the reservoir by injecting highly pressurized fluids into the well. The fracturing fluids carry particles known as *proppants* that “prop open” the fracture. Proppants include synthetic materials and clean sand of uniform particle size. The proppants can be hundreds of thousands of times more permeable than the reservoir rock, allowing petroleum to flow easily into the well and increasing the rate of production.

**Primary recovery.** During the early stages of production, the natural pressure of the petroleum deposit will force crude oil into the well. This stage is called *primary recovery*.

Over time, removing crude oil from a reservoir reduces the pressure in the reservoir. As reservoir pressure drops, the well’s production rate slows. If the reservoir contains liquid petroleum with almost no dissolved gas, removing a relatively small amount of fluid can rapidly reduce the reservoir pressure. Recovery of as little as 5 percent of the initial crude oil can make the reservoir pressure equal to the pressure at the bottom of the well. When this happens, the reservoir pressure no longer drives the oil into the well, stranding about 95 percent of the original oil in the reservoir.

Most reservoirs, however, hold crude oil that contains a significant amount of dissolved gases. As the pressure in such a reservoir decreases, more gas comes out of solution, helping to maintain pressure within the reservoir. In this type of reservoir, up to 30 percent of the original petroleum can be recovered before the pressure in the reservoir equals the pressure in the bottom of the well.

In many deposits, underground water also pushes against petroleum. The more water a reservoir contains, the more crude oil the water can drive to the surface. Water pressure can help wells extract 35 to 50 percent or more of the crude oil in a reservoir.

As reservoir pressure declines, engineers must take steps to help the petroleum reach the top of the well. They can extract gas from the top of the reservoir and inject it into the bottom of the well. The gas dissolves into the crude oil at the bottom of the well, reducing its density. Less pressure is required to drive the less dense fluid to the surface.

Engineers can also use a pump to reduce the pressure inside the well, drawing more petroleum to the surface. The most common pumping device is the *beam pump*. This device gets its name from a long steel beam that rocks like a seesaw as the pumping mechanism connected to it goes up and down inside the well.

Eventually, water will seep into the well. The most expensive activity in petroleum production is the removing and disposing of water. Crews usually dispose of water by injecting it into



another underground reservoir.

Eventually, the production rate of an oil well will drop dramatically. Lower production may result from many factors, including a drop in permeability or reservoir pressure, or the increased production of water. A petroleum reservoir is said to be *mature* when production at its wells slows and becomes more expensive.

**Secondary and tertiary recovery.** A mature petroleum reservoir, however, still contains most of its original petroleum. Engineers use many techniques to coax more petroleum from the wells. All of these techniques involve injecting fluids into strategically placed wells to push petroleum into the producing wells.

The most common technique used to produce oil from a mature reservoir is called *secondary recovery* or *waterflooding*. In this technique, the drillers inject water into the bottom of a reservoir. As water levels at the bottom of the reservoir rise, they force petroleum into the producing wells. Secondary recovery often uses water that has been recovered from the reservoir during primary recovery.

Other techniques called *tertiary recovery* or *enhanced oil recovery* methods extract crude oil that remains trapped in the rock. Tertiary recovery techniques are often too expensive to extract petroleum at a profit.

In tertiary recovery, engineers often inject chemicals called *surfactants* into the well. Surfactants are soaps that literally wash oil from reservoir rocks. A similar technique treats the reservoir with *miscible floods*, injections of polymers mixed into water. The polymers make the water viscous enough to sweep liquid petroleum toward the producing wells. If the water were not so viscous, it would push through the petroleum and flow into the producing wells.

The most common and successful tertiary recovery technique is called *thermal recovery*. In thermal recovery, engineers pump hot water or steam into a mature oil reservoir. Engineers use this technique to produce heavy crude oils that are so viscous that they do not flow. The steam or water reduces the viscosity of the oil, allowing it to flow into the producing wells.

Natural and artificial recovery techniques still leave a large part of the original petroleum in place. In even the most mature and heavily produced reservoirs, more oil may remain than has been brought to the surface. Production ceases when extracting the oil becomes too expensive to be profitable.

## Transporting petroleum

After petroleum reaches the surface, devices called *separators* separate crude oil from natural gas. Other devices remove water from both substances.



Some petroleum companies inject unwanted natural gas back into the reservoir. Other companies pump natural gas into a pipeline for transportation to a processing facility. If a pipeline is unavailable or inadequate, the natural gas may be converted into a liquid by cooling it. Gas that has been liquefied in this way is called *liquefied natural gas* (LNG). LNG may take up  $\frac{1}{600}$  as much storage space as the same amount of unliquefied gas. For information on how natural gas is transported and processed, see Gas.

Crude oil travels over land from the oil well to the refinery through pipelines. Pipelines may carry the oil from a few miles or kilometers to hundreds of miles or kilometers. One of the best-known pipelines, the Trans-Alaska Pipeline, stretches about 800 miles (1,300 kilometers) from oil fields on Alaska's North Slope near the Arctic Ocean to the port of Valdez on the coast of the Pacific Ocean. In Canada, the Enbridge Pipeline system carries oil about 3,300 miles (5,300 kilometers) from Edmonton, Alberta, to Montreal, Quebec. The Friendship Pipeline system, which measures about 1,625 miles (2,615 kilometers), carries oil from the Ural Mountains in Russia to other countries of Europe.

Where oceans and seas are available, special ships called tankers carry petroleum. Some tankers can hold more than 1 million barrels of petroleum. A petroleum barrel holds 42 gallons (159 liters). Tankers carry most of the oil transported between nations.

## Refining petroleum

Crude oil arrives at a petroleum refinery, a maze of towers, tanks, and pipes. Refineries hum with activity day and night. They can operate continuously for years before being shut down for repairs. Refineries range in size from small plants that process about 150 barrels of crude oil a day to giant complexes with a daily capacity of more than 600,000 barrels.

A refinery converts crude oil into useful products by separating it into its various fractions. The fractions are then chemically changed and treated with other substances. The refining process includes (1) separation, (2) conversion, and (3) chemical treatment.

**Separation.** The first stage in petroleum refining is *fractional distillation*. Fractional distillation separates crude oil into some of its fractions. Additional fractions may be separated from these fractions by processes called *solvent extraction* and *dewaxing*.

**Fractional distillation** is based on the principle that different fractions have different boiling points. As crude oil is heated, each fraction *vaporizes* (turns into a gas or vapor) at its boiling point. For example, gasoline vaporizes at about 90 °F (32 °C), while some of the heavy fuel oils have boiling points higher than 600 °F (316 °C). As a vaporized fraction's temperature falls below its boiling point, it *condenses* (turns into a liquid).

In fractional distillation, crude oil is pumped through pipes inside a furnace and heated to temperatures of over 650 °F (343 °C). The resulting mixture of hot gases and liquids then passes into a vertical steel cylinder called a *fractionating tower* or *bubble tower*. A fractionating tower is divided into several different levels. The bottom level of the tower is the hottest. Each level above the bottom is slightly cooler than the one below. As vaporized petroleum rises through the tower, fractions condense when the temperature drops below



their boiling point. Heavy fuel oils condense in the lower sections. Lighter fractions, such as gasoline and kerosene, condense in the middle and upper sections. At each level, condensing fractions collect in trays and are drawn off by pipes along the sides of the tower.

Some fractions do not cool enough to condense. They pass out of the top of the fractionating tower into a collection tank called the *vapor recovery unit*. Other fractions, which vaporize at temperatures higher than those in the furnace, remain as liquids or semisolids. These *residues* are recovered from the bottom of the tower and refined into such products as asphalt and lubricating oils.

Fractions produced by fractional distillation are called *straight-run products*. Almost all of them must undergo conversion and chemical treatment before they can be used.

**Solvent extraction** separates additional fractions from certain straight-run products. A chemical called a *solvent* either dissolves some of the fractions or causes them to separate out as solids. The principal solvents used include *furfural* and *phenol*. Many refineries improve the quality of gasoline, kerosene, and lubricating oils by solvent extraction.

**Dewaxing**, also called *crystallization*, is used chiefly to remove wax and other semisolid substances from heavy fractions. The fractions are cooled to a temperature at which these heavier substances form crystals or solidify. They are then put through a filter that separates out the solid particles.

**Conversion.** Although nearly all petroleum can be refined into useful products, some fractions are much more valuable than others. Gasoline, for example, accounts for nearly 50 percent of the crude oil used in the United States. Gasoline, however, makes up only a small percentage of the straight-run products. Many less valuable fractions make up a higher percentage of crude oil.

Scientists have developed several methods to convert less useful fractions into more valuable fractions. These methods fall into three main groups: (1) cracking processes, (2) combining processes, and (3) reforming processes. Conversion allows refiners to produce about half a barrel of gasoline from each barrel of crude oil.

**Cracking processes** convert heavy fractions into lighter ones, mainly gasoline. These processes not only increase the quantity of gasoline obtained from oil but also improve the quality. Gasoline produced by cracking has a higher *octane number* than the straight-run product. Octane number is a measure of how smoothly fuel burns in an engine. See Octane number.

There are two principal types of cracking processes—*thermal cracking* and *catalytic cracking*. In thermal cracking, heavy fractions are subjected to intense heat and pressure to weaken the bonds that hold large, complex molecules together. The heat and pressure *crack* (break down) these molecules into the simpler ones that make up light fractions.

In catalytic cracking, a *catalyst* is used to accelerate the thermal cracking process. A catalyst



is a substance that sets off or speeds up a chemical reaction without being changed by the reaction. In this form of cracking, the fractions are heated and then passed over minerals called *zeolites* or other catalysts. The combination of heat and catalytic action causes the heavy fractions to crack into lighter ones. Catalytic cracking is more widely used than thermal cracking alone because it requires less pressure and produces higher-octane gasoline.

During cracking, hydrogen may be added to the fractions. This procedure, known as *hydrocracking*, further increases the yield of high quality gasoline and other useful products.

**Combining processes** do the reverse of cracking. They combine simple gaseous hydrocarbons to form more complex fractions. As a result, many of the gases produced by distillation and cracking are converted into high-octane liquid fuels and valuable chemicals. The major combining processes include *polymerization* and *alkylation*.

In polymerization, gases are subjected to heat and pressure in the presence of a catalyst. The hydrocarbon molecules unite to form polymers. Polymers are effective ingredients in high-octane gasoline. Alkylation is similar to polymerization. It produces a fraction called *alkylate*, which is used in both aviation fuel and gasoline.

**Reforming processes** use heat and a catalyst to rearrange the molecules of a fraction so that they form different hydrocarbon groups. Instead of breaking the molecules apart or combining them, reforming changes their structure. Reforming produces high-octane fuels and *aromatics*, which are chemicals used in making explosives, plastics, food preservatives, and many other products.

**Chemical treatment.** Nearly all fractions are chemically treated before they are sent to consumers. The method of treatment depends on the type of crude oil and on the intended use of the petroleum product.

Many fractions are treated to remove impurities. The most common impurities are sulfur compounds, which can damage machinery and pollute the air when burned. Treatment with hydrogen is a widely used method of removing sulfur compounds. In this method, called *hydrotreating*, fractions are mixed with hydrogen, heated, and then exposed to a catalyst. The sulfur in the fractions combines with the hydrogen, forming the gas hydrogen sulfide. The hydrogen sulfide is then trapped in a vapor recovery unit.

Some fractions perform better if they are blended or combined with other substances. For example, refineries blend various lubricating oils to obtain different degrees of viscosity. Gasoline is blended with chemicals called *additives*, which help it burn more smoothly and give it other special properties.

Once refining processes are complete, such fractions as gasoline and kerosene are shipped to fueling stations. Other fractions are sent to factories for use in manufacturing. These products travel from the refinery by pipeline, truck, railroad, or ship to their final destinations.



## Environmental problems

The production and use of petroleum has given rise to several environmental problems. Toxic crude oil can be spilled on land or in water, poisoning plants and animals. The burning of fuels derived from petroleum releases toxic gases that pollute the air. Some scientists even believe that the burning of petroleum fuels contributes to global climate change.

**Spills and seeps.** Petroleum can spill during many stages of its production, transportation, and consumption. Petroleum can leak from wells on land or in the sea. Pipelines can break, causing petroleum to spill during transportation. Oil tankers may collide or sink, releasing huge loads of crude oil into the water. Accidents or disasters can cause toxic petroleum products to spill from power plants, refineries, and even gasoline stations. Some petroleum also seeps naturally from openings in the sea floor.

Spills and seeps release about 15 million barrels of crude oil into the environment each year. This makes up only about 1/5 of the oil consumed in one day. About 10 percent of this oil seeps naturally from the ocean floor. Petroleum companies spill about 28 percent of this oil during production and transportation. The remaining 62 percent is released in spills during industrial and private consumption.

Although only a small fraction of petroleum produced is spilled, petroleum spills are a major environmental problem. Most of the chemicals in petroleum are toxic to living things. Damaging effects from oil spills can persist in an area for decades. The oil may also spread far from the location of the spill. In 2010, for example, an explosion at the *Deepwater Horizon* oil rig spilled around 134 million gallons (507 million liters) of oil into the Gulf of Mexico. The oil spread from the rig—about 50 miles (80 kilometers) off Louisiana—to the coasts of a number of Gulf states. Oil spills can be difficult and expensive to clean up.

**Air pollution.** The burning of petroleum fuels generates exhaust gases and particles that pollute the air. Petroleum fuels burned to power vehicles, heat homes and businesses, and generate electric power are a leading cause of air pollution in many countries.

Burning petroleum fuels generates gases, such as carbon monoxide, sulfur dioxide, and nitrogen oxides. These gases are poisonous to plants, animals, and people. Sulfur dioxide and nitrogen oxides can combine with water in the atmosphere, raising the water's acidity. This water can then fall back to the surface, where it can damage property and pollute the environment. This phenomenon is known as *acid rain*. Since the 1970's, many industries have taken steps to reduce the emissions of these gases. However, these forms of pollution remain a problem in some areas.

In general, burning liquid fuels derived from petroleum produces less pollution than burning an equivalent amount of coal. Burning natural gas creates much less pollution than burning liquid petroleum fuels. Burning natural gas produces no sulfur dioxide and no solid particles.

**Global warming.** Nearly all climate scientists consider petroleum use to be a major factor in global climate change. Earth's average surface temperature has risen sharply since the



mid-1900's. Scientists believe increasing concentrations of *greenhouse gases* are responsible for most of this warming. Greenhouse gases, such as methane and carbon dioxide, act much like the glass walls of a greenhouse. They trap heat from the sun and hold it near Earth's surface. Scientists predict that global warming, if left unchecked, will damage human society and the environment. For example, global warming could melt enough of the ice on land near Earth's poles to raise the sea level. It could also risk extinction for many plant and animal species.

Carbon dioxide makes up the largest portion of waste gases produced by burning petroleum. The concentration of carbon dioxide in the atmosphere has risen by nearly 40 percent since 1750. During the Industrial Revolution, which began in the late 1700's, people began burning large amounts of petroleum and coal as power-driven machinery largely replaced hand labor.

## The price of petroleum

Because petroleum is such an important source of energy, the price of petroleum is often a major concern. Petroleum prices rise and fall according to supply and demand.

**How prices are set.** Petroleum prices are determined in a special market called a *commodity exchange*. In such an exchange, buyers bid on contracts called *futures contracts*. A futures contract is an agreement by a petroleum producer to deliver a certain amount of petroleum on a certain date at a prearranged price. The auctioning of futures contracts determines fair market prices for petroleum, which are then published.

Futures contracts measure crude oil and natural gas in standard units. Crude oil is measured in *barrels*. One barrel equals 42 gallons (159 liters) of petroleum. Natural gas is measured in *thousands of cubic feet* (Mcf). One Mcf equals 1,000 cubic feet (28 cubic meters) of natural gas at a set temperature and pressure.

Crude oils vary greatly in quality and value. For this reason, crude oil prices are based on *benchmark crudes*, crude oils considered to be of average value. Two commonly used benchmark crudes are West Texas Intermediate Crude and Brent Crude. West Texas Intermediate Crude is a blend of oil from fields in western Texas. Brent Crude comes from the North Sea. A barrel of light crude often sells for higher than the benchmark price. Barrels of heavy crude often sell for less.

**How prices change.** Petroleum prices rise and fall according to demand for petroleum and the supply available to meet that demand. In general, an increase in demand causes prices to rise. An increase in supply can cause prices to fall.

As petroleum prices rise, petroleum companies invest more money in exploration. They may also begin producing petroleum from reservoirs that were once considered unprofitable. These activities increase the supply of petroleum, causing prices to fall. As prices fall, petroleum companies slow exploration and stop producing petroleum from some wells. Eventually, the supply begins to fall, and prices rise once again.



Other factors, such as news of wars, natural disasters, civil unrest, or terrorist attacks, can also influence the price of petroleum. Such news may convince investors that the future supply of petroleum could be interrupted. Investors then buy more petroleum, causing prices to rise. Prices may fall again when a conflict or disaster ends.

## **Petroleum and international relations**

The world's petroleum resources are not distributed equally. Some countries, especially those in the Middle East, tend to produce much more petroleum than they can use. On the other hand, the United States, Japan, and several countries in Western Europe use far more petroleum than they can produce. These countries must import most of the petroleum they use. The economies of all countries depend to some degree on the import or export of petroleum. For this reason, petroleum can complicate international relations and lead to disagreements, conflicts, or even war.

**The petroleum gap.** The countries that consume the most petroleum are also the world's wealthiest and most industrialized. Petroleum-producing nations tend to be, in general, smaller and poorer. This inequality can create resentment and mistrust between petroleum-producing and petroleum-consuming nations.

As with any valuable resource, petroleum can also create political and social instability where it is found. In a petroleum-producing region, the people who control the petroleum are often richer and more powerful than the people who do not. This inequality can anger people who feel that petroleum resources and profits are distributed unfairly.

**Petroleum and diplomacy.** For countries that depend on imported petroleum, the security of the petroleum supply is a major concern. Petroleum may be produced in one country, be refined in another, and pass through several nations before it arrives at its final destination. The need to stay on friendly terms with all of the countries along this petroleum pathway is a major challenge in international relations.

At any point during production or consumption, petroleum may pass through areas made unstable by political unrest, ethnic and religious strife, or disputes between neighboring countries. When situations like these threaten the petroleum supply, the nations that depend on petroleum can find it difficult or even impossible to resist becoming involved in such conflicts.

**Petroleum and war.** Historians have argued that petroleum influenced the course of many modern wars. For example, during World War II (1939-1945), rival petroleum-consuming nations fought battles for the control of petroleum-producing regions.

More recent conflicts have pitted petroleum-producing nations against each other and against petroleum-consuming nations. These include the Iran-Iraq War (1980-1988), the Persian Gulf War of 1991, and the Iraq War (2003-2011). All of these wars had causes not directly related to petroleum. Political scientists have argued, however, that the need to secure the petroleum supply helped persuade the opposing countries to engage in these



conflicts.

**Petroleum and security.** Since the 1970's, many people have become concerned about the link between petroleum and national security. Many modern terrorists come from petroleum-producing countries in the Middle East. These terrorists include those directly involved in the Sept. 11, 2001, terrorist attacks on the World Trade Center in New York City and the Pentagon near Washington, D.C. Some people worry that dependence on petroleum from the Middle East will complicate efforts to find and arrest terrorists. Other people express concern that petroleum profits support oppressive or hostile governments.

Many people also worry that the need to secure the petroleum supply influences petroleum-consuming countries to intervene too much in conflicts between petroleum-producing nations. Some fear that this intervention could incite the hatred of terrorists.

**Environmental issues** also pose a challenge to international relations. Efforts to reduce pollution often require the cooperation of many different nations. For example, in 1997, many nations drafted an agreement called the Kyoto Protocol. The agreement, which went into effect in 2005, called upon industrial nations to reduce greenhouse gas emissions in an effort to control global warming. The United States refused to participate in the protocol.

## History of petroleum use

People have used petroleum for thousands of years. Before the 1850's, people relied on the relatively small amounts of crude oil that seeped to Earth's surface naturally or was extracted during salt mining. They used this oil to make construction materials, adhesives, lubricants, ointments, and fuel for lamps.

The petroleum industry soon filled the growing demand for kerosene to fuel lamps. In the 1850's, kerosene had begun to replace more expensive lamp fuels, such as *camphene* (a product of turpentine) and whale oils. At first, kerosene was produced by extracting it from coal and shale. Refining crude oil produced kerosene much more efficiently. The demand for kerosene drove oil prices to about \$15 per barrel at the beginning of 1860. By the end of 1861, extensive drilling had produced much more oil than people could use. Prices plunged to 10 cents per barrel.

**Beginnings of the petroleum industry.** Most historians trace the beginning of the petroleum industry to 1859. In that year, "Colonel" Edwin L. Drake, a former railroad conductor, drilled an oil well near Titusville, Pennsylvania. Drake used equipment designed to drill saltwater wells. His well reached  $69\frac{1}{2}$  feet (21.2 meters) deep.

**Growth of the petroleum industry.** Prospectors soon discovered that other states had large oil deposits, too. By the mid-1870's, commercial production of oil had begun in California, New York, Ohio, and West Virginia. Several more states followed in the 1880's. In 1901, prospectors opened the first well at what came to be known as the Spindletop oil field



in eastern Texas. The well gained fame as a *gusher*, an oil well that produces a great amount of oil without pumping. During the 1890's and early 1900's, California and Oklahoma joined Texas as the leading oil-producing states. Annual U.S. oil production rose from 2,000 barrels in 1859 to nearly 64 million barrels in 1900.

Interest in commercial oil production spread rapidly throughout the world. European countries began importing crude oil from the United States. Belgium, France, Germany, the Netherlands, and the United Kingdom opened refineries in the late 1860's. Other countries, including what are now Canada, India, Indonesia, Myanmar, Poland, Romania, and Russia, also began producing oil in the late 1800's.

Around 1900, two trends dramatically changed the petroleum industry—electric lights were replacing kerosene lamps, and the automobile was becoming increasingly popular. The automobile created a strong demand for gasoline as the demand for kerosene declined. At that time, however, only a small amount of gasoline could be produced from a barrel of crude oil. The introduction of the thermal-cracking process in 1913 helped solve the problem. Within five years, refiners had more than doubled the amount of gasoline that they could produce from a barrel of crude oil.

**World War I (1914-1918).** Industry developed rapidly in the early 1900's, creating an increased demand for petroleum. Some countries, such as the United States and Russia, had their own petroleum reserves. Other nations, such as the United Kingdom and the Netherlands, imported oil from colonies or other areas under their control. Still other industrial countries, such as Germany, lacked access to large reserves of petroleum. Competition between industrialized powers for petroleum-producing colonies helped contribute to the outbreak of World War I.

Petroleum also affected the outcome of World War I. For the first time, motorized vehicles powered by petroleum competed against the power of steam, horses, and human muscles. By the end of the war, battleships, armored vehicles, and aircraft provided a huge military advantage, especially to nations, such as the United States and the United Kingdom, that had access to large stores of petroleum. The British navy, powered by petroleum, proved faster and more flexible than the coal-driven German Navy. Petroleum-powered vehicles on land, air, and sea helped bring victory to the United States, the United Kingdom, France, Russia, and their allies.

**Between the wars.** After World War I, the use of petroleum brought about major changes on farms. More and more farmers began to operate tractors and other equipment powered by petroleum. Petroleum power had become an important part of nearly every industry. Petroleum quickly became a vital resource.

The first important petroleum discoveries in the Middle East had occurred in Iran in 1908. Prospectors located huge petroleum deposits in Iraq in 1927, in Bahrain in 1932, and in Saudi Arabia in 1938. Large petroleum deposits were later found in other Middle Eastern nations. The Middle East eventually became the most important petroleum-producing region in the world.



**World War II (1939-1945).** Petroleum also strongly influenced the course of World War II. During the war, petroleum from the Middle East helped fuel the Allied war effort. Allied and Axis forces fought military campaigns for control oil resources in the Middle East and other parts of the world.

When the war began, Germany lacked control of significant petroleum resources. The country's need for petroleum was one of the major causes of a disastrous attempt to invade the Soviet Union. In 1942, German forces drove toward oil fields in the Caucasus Mountains, then in the Soviet Union, now in Azerbaijan. Soviet forces defeated the Germans at the Soviet city of Stalingrad (now Volgograd) in one of the bloodiest battles in history. Many historians cite Germany's lack of petroleum as a major cause of that country's defeat.

Petroleum also helped lead to war in the Pacific. Japan's economy had grown rapidly during the early 1900's. In 1931, the country's increasing demand for petroleum and other resources led it to seize Manchuria, a region of China rich in natural resources. By 1941, Japan had seized other petroleum-producing areas of China and Southeast Asia. In response, the United States stopped exporting petroleum to Japan.

In 1941, Japan attacked U.S. military bases at Pearl Harbor in Hawaii. The United States responded by declaring war against Japan. The two nations fought many battles for control of the petroleum supply. To obtain petroleum from the Dutch East Indies (now Indonesia)—Japanese forces occupied that colony in 1942. In that year, the U.S. Navy had begun attacking Japanese oil tankers. Allied forces had completely cut off Japan's oil supply by early 1945. Petroleum shortages severely crippled Japan's ability to wage war.

**The postwar period.** After World War II, increased industrialization and rapid population growth created new and greater demands for petroleum. In the United States, a boom in sales of single-family houses, electrical appliances, and motor vehicles led to great increases in the consumption of petroleum. By the end of the 1960's, the United States accounted for more than 30 percent of the world's petroleum consumption.

During the 1960's, prospectors discovered significant amounts of petroleum in northern Alaska and in the North Sea off northwestern Europe. The new reserves, however, were not large enough to satisfy the increasing demand. Increasingly, industrialized nations relied on petroleum produced in the Middle East.

For much of the history of the petroleum industry, American and European companies owned or operated the petroleum industry in many Middle Eastern countries. In 1951, Iran became the first such country to take over the holdings of foreign firms. By the mid-1970's, most nations in the Middle East either fully controlled or held a majority interest in their petroleum industry.

In 1960, Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela formed the Organization of the Petroleum Exporting Countries (OPEC). OPEC is a group of nations whose economies depend on the export of petroleum. Several more countries have joined OPEC since then. OPEC nations seek to control petroleum prices by controlling the amount of petroleum they produce.



**The energy crisis.** Adjusting for inflation, the price of oil remained largely stable from 1870 to 1970. During the late 1960's and early 1970's, political instability in the Middle East disrupted the flow of oil to the major industrialized countries. In 1971, OPEC's member nations, which held most of the world's petroleum reserves, acted to raise the price of oil by reducing production. Political instability and production cuts pushed oil prices from less than \$3.00 per barrel in 1973 to a peak of \$34 per barrel in 1981.

This steep price increase forced many countries to begin energy-conservation programs. In addition, petroleum exploration increased throughout the world. Prospectors discovered new petroleum reserves in Angola, Brazil, and Papua New Guinea.

**Falling prices.** Conservation and exploration helped to increase the petroleum supply. This led prices to fall by about 50 percent between 1985 and 1986. The price decline created economic problems in developing countries whose economies relied on the export of petroleum. Many economists believe that falling petroleum prices also contributed to the collapse of the Soviet Union in 1991. The Soviet economy had relied heavily on petroleum exports to the West. For the most part, oil export prices remained low throughout the 1990's.

In the late 1990's, an economic downturn in Asia reduced the demand for petroleum, causing prices to drop below \$12 per barrel in 1998. OPEC responded by reducing exports, causing prices to double by 2000.

**Wars against Iraq.** In 1990, Iraq invaded Kuwait, in part in an attempt to gain control of the country's petroleum reserves. The Iraqi government also desired better access to shipping ports used to transport petroleum. The United Nations (UN) responded by banning the import of most Iraqi products, including oil. In 1991, a coalition organized by the United States and the UN expelled Iraqi forces from Kuwait. This conflict became known as the Persian Gulf War of 1991.

In 2003, a coalition of nations led by the United States and the United Kingdom invaded Iraq in an effort to oust Iraqi president Saddam Hussein. Following the collapse of Hussein's government, many nations lifted their ban on imports of Iraqi oil. The coalition vowed to use profits from Iraq's petroleum to help rebuild the country.

In 2002 and 2003, political unrest and a series of strikes reduced petroleum production in Venezuela. The reduction, along with the Iraq War (2003-2011), helped to keep oil prices relatively high.

## The future of petroleum

The world's petroleum supply will not last forever. A limited amount of petroleum exists beneath the ground, and petroleum companies probably cannot extract all that is there. At current rates of consumption, the world's recoverable crude oil reserves could run out in the mid-2000's.



Increasing use of natural gas could help extend the petroleum supply. Some petroleum experts believe that switching to natural gas for much of our energy needs could help the petroleum supply last until about 2200. In addition to being mined from petroleum deposits, natural gas can be extracted from coal. Natural gas also exists in the form of *natural gas hydrates*, frozen deposits of methane and water ice found in cold regions and beneath the ocean floor. Improved methods for extracting natural gas and crude oil could extend the petroleum supply until about 2300.

Eventually, alternative energy sources will have to replace petroleum. Renewable energies, such as solar power, wind power, and water power, may replace petroleum in some areas. Nuclear power can also help replace the vast amounts of energy that petroleum provides. This power may come from the splitting of atoms, called *fission*, or the combining of atoms, called *fusion*.

Fission reactors produce electric power in about 30 countries. But most fission power plants rely on a scarce type of uranium, supplies of which will dwindle by 2100. Fission also creates radioactive wastes that can remain dangerous for thousands of years. Fusion, if perfected, could provide a cleaner and more efficient power source than fission. Fusion, however, only takes place in a tremendously hot state of matter called *plasma*. Scientists have not yet invented an effective way to contain plasma needed for fusion power.

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