Coal is the most plentiful fuel in the fossil family. The United States has more coal reserves than any other country in the world. In fact, one-fourth of all known coal in the world is in the United States, with large deposits located in 38 states. The United States has almost as much energy in coal that can be mined as the rest of the world has in oil that can be pumped from the ground.

Lignite Coal

Primarily found west of the Mississippi River in the United States

Subbituminous Coal

Mined in Montana and Wyoming

Bituminous Coal

Primarily found east of the Mississippi River

Anthracite Coal

The U.S. reserves are found primarily in Pennsylvania

TYPES OF COAL

Coal is a black rock made up of large amounts of carbon. Like all fossil fuels, coal can be burned to release energy. Coal contains elements such as hydrogen, oxygen, and nitrogen; has various amounts of minerals; and is itself considered to be a mineral of organic origin.

Due to the variety of materials buried over time in the creation of fossil fuels and the length of time the coal was forming, several types were created. Depending upon its composition, each type of coal burns differently and releases different types of emissions.

The four types (or "**ranks**") of coal mined today:

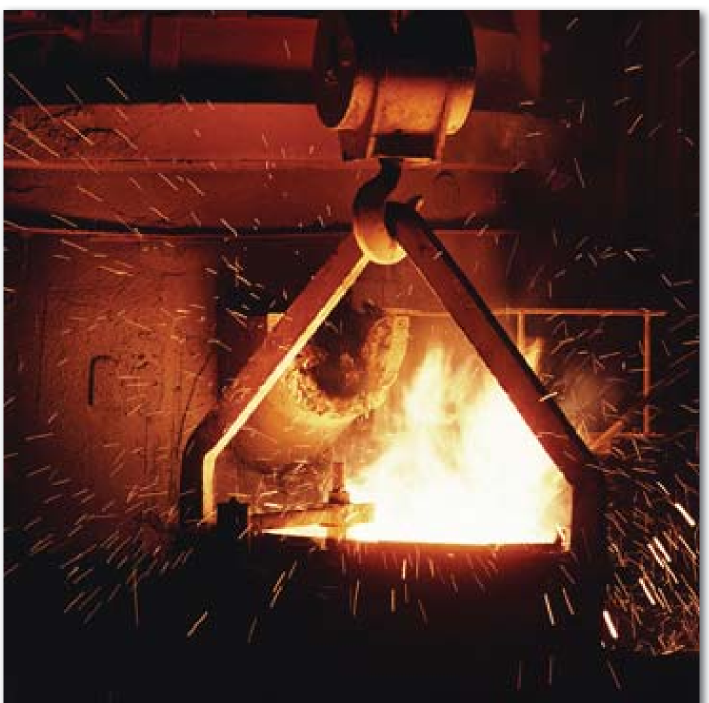
- **Lignite** makes up the largest portion of the world's coal reserves. A soft, brownish-black coal, lignite forms the lowest level of the coal family. The texture of the original wood can even be seen in some pieces primarily found west of the Mississippi River.
- **Subbituminous** is next on the scale. It is a dull black coal. It gives off a little more energy (heat) than lignite when burned. It is mined mostly in Montana, Wyoming, and a few other western states.
- **Bituminous** has even more energy. Sometimes called "**soft coal**," it is found primarily east of the Mississippi River in midwestern states like Ohio and Illinois and in the Appalachian mountain range from Kentucky to Pennsylvania.
- **Anthracite** is the hardest coal and gives off the greatest amount of heat when burned. Unfortunately, in the U. S., as elsewhere in the world, there is little anthracite coal to be mined. The U.S. reserves of anthracite are located primarily in Pennsylvania

HOW WE USE COAL

In the United States, coal is used primarily to generate electricity. Nine out of every 10 tons of coal consumed in the United States are used for this purpose. It is burned in power plants to produce nearly half of the electricity we use each year. Do you know that your house can use more than a ton of coal in one year? If your house has an electric stove and water heater, roughly a ton of coal a year is needed to run these appliances. Another half ton of coal a year keeps your refrigerator running. With nearly 300 billion tons of recoverable coal located in the United States, we have enough to last more than 250 years if we

In the United States,

coal burned in power plants produces nearly half of the electricity we use each year.



The very high temperatures,

made possible by the use of coke (coal baked in hot furnaces), give steel the strength and flexibility needed for making bridges, buildings, and automobiles.

continue to use coal at the same rate as we use it today.

Coal is also used in the industrial and manufacturing industries. The steel industry, for example, uses large amounts of coal. The coal is baked in hot furnaces to make **coke**, which is used to smelt iron ore into the iron needed for making steel. The very high temperatures created from the use of coke gives steel the strength and flexibility needed for making bridges, buildings, and automobiles.

Coal's heat and by-products are also used to make a variety of products. For example, methanol and ethylene—ingredients in coal that can be separated out—can be used to make plastics, tar, synthetic fibers, fertilizers, and medicines.

The United States exports about 5 percent of the coal mined in the country. In 2008, 59.1 million short tons of coal were exported to other countries, including Canada, Brazil, and Italy. More than half of the coal exports are used for making steel.

HOW WE MINE COAL

In the United States, coal is currently mined in 25 states, primarily by using either surface mining techniques or underground methods.

Surface mining accounts for about 60 percent of the coal produced in the United States. It is used mostly in the West where huge coal deposits lie near the surface and can be up to 100 feet thick.

In surface mining, bulldozers clear and level the mining area. Topsoil is removed and stored for later use in the land reclamation process. Specially designed machines —draglines, or large shovels—clear away the **overburden** (material overlaying coal that must be removed before mining can commence) to expose the coal bed. Smaller shovels load the coal into large trucks that remove the coal from the pit.

Before mining begins, coal companies must post bonds for each acre of land to be mined to assure that it will be properly reclaimed. In the reclamation process, first the overburden, then the soils are replaced and the area restored as nearly as possible to its original contours. Since 1977, more than 2 million acres of coal mine lands have been reclaimed in this manner.

Where coal seams are too deep or the land is too hilly for surface mining, coal miners must go underground to extract the coal. Most underground mining takes place east of the Mississippi, especially in the Appalachian mountain states and is used to produce about 30 percent of U.S. coal today.

The type of **underground mine** technique used is determined by how the coal seam is situated. If a coal outcrop appears at the surface of a hillside, a "**drift mine**" can be driven horizontally into the seam. Where the bed of coal is close to the surface, yet too deep for surface mining, a **slope mine** can be constructed with the mine shaft slanting downward from the surface to the coal seam. To reach deeper seams, which may be as much as 2,000 feet below the surface, vertical shafts are cut through the overburden.

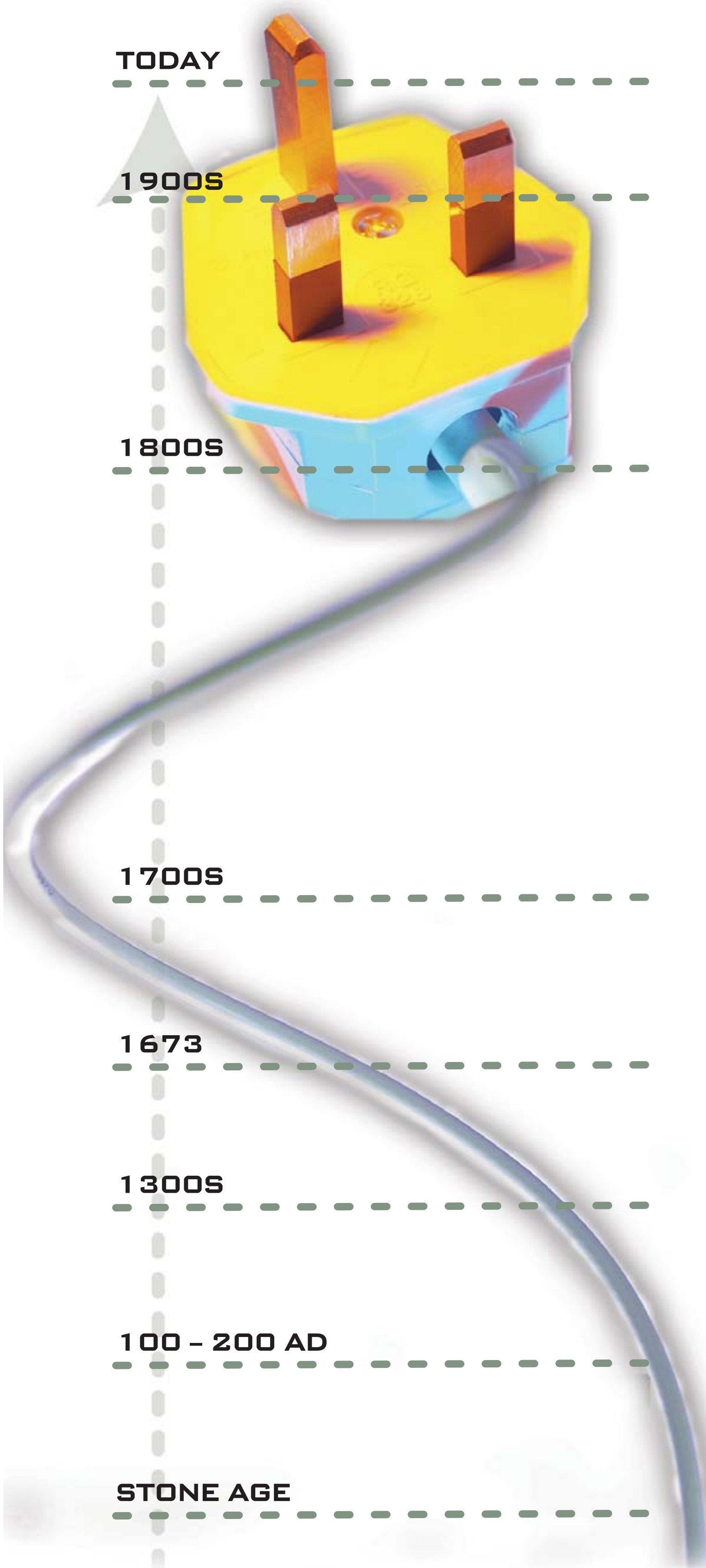
Underground mining today is highly mechanized. The principal methods of production are machines called "**longwall miners**" and "**continuous miners**." In longwall mining, a cutter moves under a long panel of hydraulic roof supports which protect the coal miners and move forward as work progresses. As the coal is cut from the seam, it falls onto a conveyor belt that removes it from the mine. Longwall mining accounts for more than half of the coal produced underground.

Continuous mining is associated with another common method of extracting coal from underground, the "**room-and-pillar**" method. A continuous mining machine breaks coal from the face of the seam with tungsten bits on a revolving cylinder then moves the coal onto a conveyor belt for transport to the surface. After advancing a specified distance, the continuous miner is backed out and roof bolts are driven into the ceiling of the mined area to bind several layers of strata into a layer strong enough to support its weight. In a "room-and-pillar" mine, coal is extracted in carefully engineered patterns, leaving large columns of coal behind to help support the roof. As much as half the coal remains in the mine in the form of these pillars.

Rocklick Coal Mine, West Virginia

Shot of a coal yard showing conveyor belts

HISTORY OF COAL



TODAY

Coal is used to generate nearly half of the electricity used in the United States.

1900S

By 1910, coal accounts for more than three-quarters of the total energy used in the United States, but is later supplanted by oil and natural gas for transportation and residential applications. It re-emerges later as an affordable, abundant domestic energy resource to support the growing demand for electricity.

1800S

James Watt invents the steam engine and uses coal to make the steam to run the engine.

The Industrial Revolution spreads to the U.S. as steamships and steam-powered railroads become the main forms of transportation, using coal to fuel their broilers.

Late 1800s: During the Civil War, weapons factories begin using coal. By 1875, coke replaces charcoal as the primary fuel for iron blast furnaces to make steel.

1880s: Coal is first used to generate electricity for homes and factories.

1700S

The English find coal produces a fuel that burns cleaner and hotter than wood charcoal.
1740s: Commercial coal mines begin operation in Virginia.

1673

Explorers to the United States discover coal.

1300S

In the U.S. southwest, Hopi Indians use coal for heating.

100 – 200 AD

The Romans use coal for heating.

STONE AGE

It is believed coal was used for heating and cooking.

COAL AND THE ENVIRONMENT

While we may rely on coal for nearly half of our electricity, it is far from being the perfect fuel. Coal contains traces of impurities like **sulfur** and **nitrogen**. When coal burns, these impurities are released into the air, where they can combine with water vapor (for example, in clouds) and form droplets that fall to earth as weak forms of sulfuric and nitric acid—called "**acid rain**." There are also tiny specks of minerals—including common dirt—mixed in coal. These particles don't burn and make up the ash left behind in a coal combustor. Some of the particles also get caught up in the swirling combustion gases and, along with water vapor, form the smoke that comes out of a coal plant's smokestack. Mercury is another potentially harmful emission contained in coal power plant emissions.

Also, coal, like all fossil fuels, is formed out of **carbon**. All living things—even people—are made up of carbon. But when coal burns, its carbon combines with oxygen in the air and forms carbon dioxide. Carbon dioxide (CO_2) is a colorless, odorless gas, but in the atmosphere, it is one of several gases that can trap the earth's heat. Many scientists believe this is causing the earth's temperature to rise, and this warming could be altering the earth's climate.

While coal used to be a dirty fuel to burn, technology advances have helped to greatly improve air quality, especially in the last 20 years. Scientists have developed ways to capture the pollutants trapped in coal before they escape into the atmosphere. Today, technology can filter out 99 percent of the tiny particles and remove more than 95 percent of the acid rain pollutants in coal, and also help control mercury. We also have new technologies that limit the release of carbon dioxide by burning coal more efficiently. Many of these technologies belong to a family of energy systems called "clean coal technologies."

Tampa Electric's Polk Power Station

One of the most advanced—and cleanest—coal power plants in the world.

TWO CURRENT CLEAN COAL TECHNOLOGIES

COAL GASIFICATION

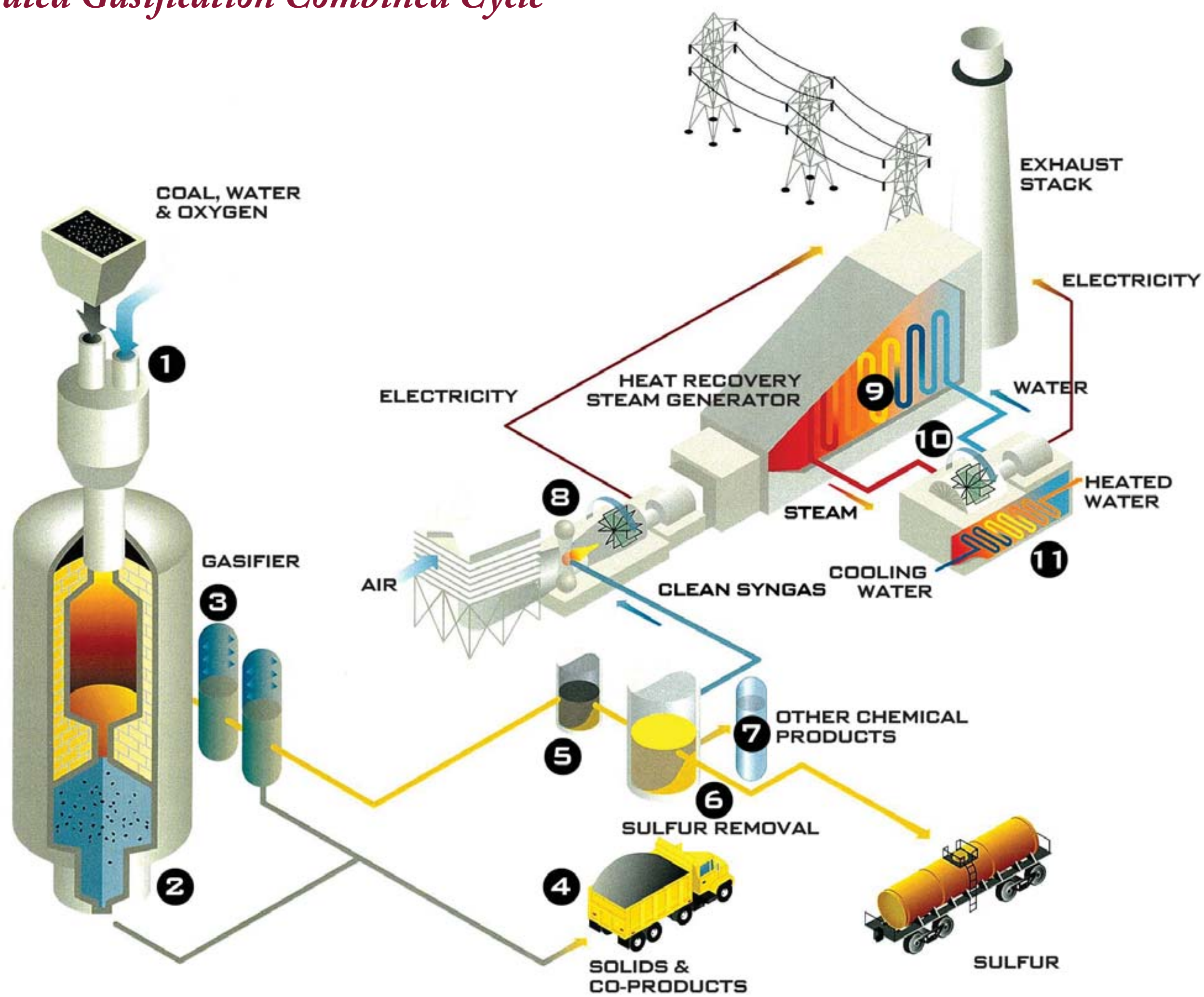
One of the most advanced—and cleanest—coal power plants in the world is Tampa Electric's Polk Power Station in Florida. Rather than burning coal, it turns coal into a gas that can be cleaned of almost all pollutants.

Coal gasification offers one of the most versatile and clean ways to convert coal into electricity, hydrogen, and other valuable energy products. Gasification, in fact, may be one of the best ways to produce clean-burning hydrogen for tomorrow's automobiles and power-generating fuel cells. Hydrogen and other coal gases can also be used to fuel power-generating turbines, or as the chemical "building blocks" for a wide range of commercial products.

Gasification breaks down coal into its basic elements. To do this, the coal is exposed to hot steam and air or oxygen under high temperatures and pressures. This causes the carbon molecules to break apart, creating a chemical reaction that will typically produce a mixture of carbon monoxide, hydrogen, and other gaseous compounds, forming what is commonly referred to as **syngas**.

CREATING ELECTRICITY WITH COAL GASIFICATION

Integrated Gasification Combined Cycle



1. Coal, water, and oxygen are fed into a high-pressure gasifier, where the coal is partially combusted and converted into synthetic gas ("syngas").

2. The ash in the coal is converted to inert, glassy slag.

3. The syngas produced in the gasifier is cooled and cleaned of particles.

4. The slag and other inert material may be used to produce other products or may be safely managed in a landfill.

5. Next, the syngas passes through a bed of activated charcoal, which captures the mercury.

6. The sulfur is removed from the syngas and converted to either elemental sulfur or sulfuric acid for sale to chemical companies or fertilizer companies.

7. The syngas can either be burned in a combustion turbine or used as a feedback for other marketable chemical products.

8. The syngas is fired in a combustion turbine that produces electricity.

9. The hot exhaust from the gas turbine passes to a Heat Recovery Steam Generator (HRSG).

10. Steam produced in the HRSG, along with additional steam that has been generated throughout the process, drives a steam turbine, which also produces electricity.

11. The steam from the turbine cools and then condenses back into water, which is then pumped back into the steam generation cycle.

illustration courtesy of American Electric Power

By using gasification, the impurities in coal—like sulfur, mercury, nitrogen, and many other trace elements—can be almost entirely filtered out when coal is changed into a gas. In fact, scientists have discovered ways to remove 99.9 percent of the sulfur and small dirt particles from the coal gas. Another benefit is that when oxygen (rather than air) is used in the gasifier, the carbon dioxide produced is in a concentrated gas stream, making it easier and less expensive to separate and capture. Once the carbon dioxide is captured, it can be sequestered—that is, prevented from escaping to the atmosphere, where it could otherwise potentially contribute to the greenhouse effect.

Additionally, the coal gases—carbon monoxide and hydrogen—don't have to be burned. They can be used as valuable chemicals. Scientists have developed chemical reactions that turn carbon monoxide and hydrogen into everything from liquid fuels for cars and trucks to plastic toothbrushes.

Another benefit to gasification is that it creates a more efficient way to produce energy. In a typical coal combustion plant, heat from the burning coal is used to boil water, which makes steam to drive a steam turbine-generator. In some of these plants, only a third of the energy value of the coal is actually converted into electricity, the rest is lost as waste heat. A coal gasification power plant, however, typically gets double duty from the gases it produces. First, the coal gases are fired in a gas turbine—much like natural gas—to generate one source of electricity. The hot exhaust of the gas turbine is then used to generate steam for use in a more conventional steam turbine-generator. This dual source of electric power, called a "**combined cycle**," is much more efficient in converting coal's energy into usable electricity. The fuel efficiency of a coal gasification power plant in this type of combined cycle can potentially be boosted to 50 percent or more, compared to the 33-40 percent efficiency common at conventional coal-based boiler plants.

Higher efficiencies translate into more economical electric power and potential savings for consumers. A more efficient plant also uses less fuel to generate power, meaning that less

Researcher

Kayenta Coal Mine

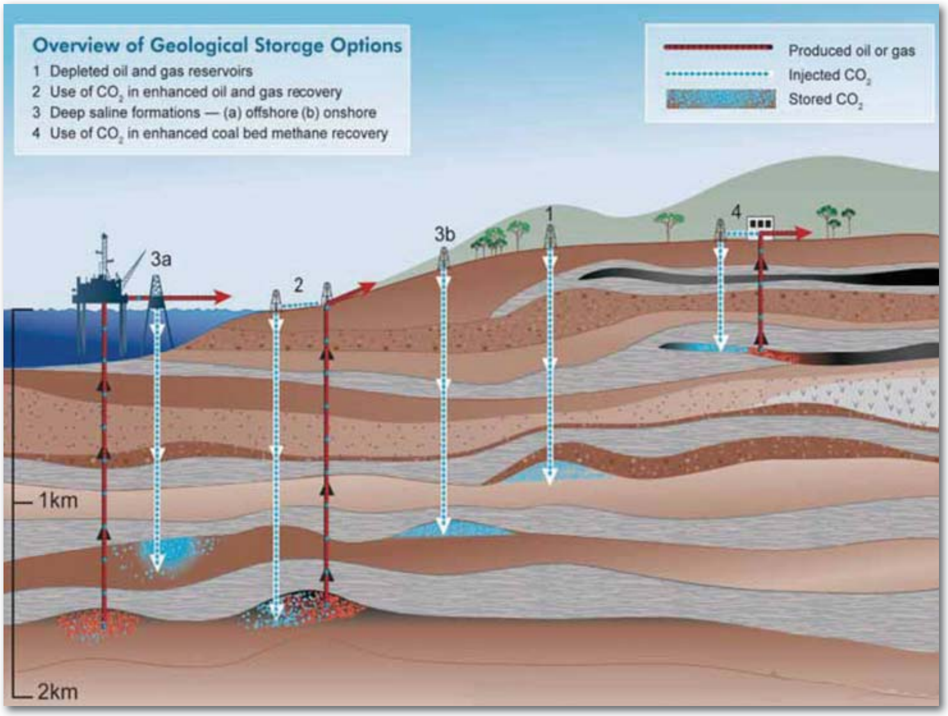
carbon dioxide is produced. In fact, coal gasification power processes under development by the U. S. Department of Energy could cut the formation of carbon dioxide by 20 – 40 percent or more, per unit of output, compared to today's conventional coal-burning plant.

CARBON SEQUESTRATION

Another approach to combating the environmental impacts of carbon dioxide on the environment is by using carbon capture and storage (CCS), a technology sometimes called **carbon sequestration**.

This technology involves the capture and long-term storage of carbon dioxide and other greenhouse gases that would otherwise be emitted into the atmosphere. The greenhouse gases can be captured at the point of emission (**direct sequestration**), or removed from the air (**indirect sequestration**). The captured gases can be stored in underground reservoirs (**geological sequestration**) or stored in vegetation and soils (**terrestrial sequestration**).

Geological sequestration involves storing carbon dioxide



in geologic formations deep underground. The formations considered for storage are layers of porous rock deep underground that are "capped" by a layer or multiple layers of non-porous rock above them. These formations include: depleted oil and gas reservoirs, unmineable coal seams, and underground saline formations.

- **Depleted Oil and Gas Reservoirs**—These are formations that held crude oil and natural gas over geologic time frames. In general, they are a layer of porous rock underneath a layer of non-porous rock that forms a dome. It is this dome shape that trapped the crude oil and natural gas. This same dome offers great potential to trap CO_2. An added benefit is that the CO_2 can enable the recovery of additional oil by expanding in the reservoir and pushing more oil to flow into the wells. This is called "**enhanced oil recovery**."
- **Unmineable Coal Seams**—Coal beds typically contain large amounts of methane-rich gas, but some are too deep or too thin for the coal to be mined economically. However, this coalbed methane can be recovered and used. The current way to recover coalbed methane is to depressurize the bed, usually by pumping water out of the reservoir. An alternative approach is to inject pressurized carbon dioxide into the bed. The porous coal surfaces absorb CO_2 more easily than methane, so the CO_2 displaces the methane and remains sequestered in the bed.
- **Underground Saline Formations**—Saline formations are layers of porous rock that are saturated with brine (salt). Underground brine formations are so common that geologists believe they could provide enough space to store all the CO_2 captured from fossil fuels burned in the 21st century. However, much less is known about saline formations than oil/gas reservoirs and coal seams; therefore, research is continuing into the possibility of using saline formations for CO_2 storage.

Terrestrial sequestration involves the removal of CO_2 from the atmosphere in terrestrial ecosystems. Vegetation and soils are widely recognized as carbon storage sinks. The earth's vegetation and soils absorbs about 2 billion tons of carbon annually, an amount equal to one third of all global carbon emissions from human activity. Significant amounts of this carbon remain stored in the roots of certain plants and in the soil. Ecosystems with significant opportunities for carbon sequestration include forests, crop lands, grasslands, deserts and degraded lands, boreal wetlands, and peat lands.

Scientists continue to research and develop carbon capture and storage technologies. It is important to make sure these processes are environmentally acceptable and safe. For example, science must determine that CO_2 will not escape from underground formations or contaminate drinking water supplies. Carbon capture and storage is an expanding area of research and development.