COAL—OUR MOST ABUNDANT FUEL

America has more coal than any other fossil fuel resource. The United States also has more coal reserves than any other single country in the world. In fact, 1/4 of all the known coal in the world is in the United States. The United States has more energy in coal that can be mined than the rest of the world has in oil that can be pumped from the ground.

Currently, coal is mined in 25 of the 50 states.

Coal is used primarily in the United States to generate electricity. In fact, it is burned in power plants to produce nearly half of the electricity we use. A stove uses about half a ton of coal a year. A water heater uses about two tons of coal a year. And a refrigerator, that's another half-ton a year. Even though you may never see coal, you use several tons of it every year!

The material that formed fossil fuels varied greatly over time as each layer was buried. As a result of these variations and the length of time the coal was forming, several types of coal 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 are: anthracite, bituminous, subbituminous, and lignite.

- **Lignite:** The largest portion of the world's coal reserves is made up of lignite, a soft, brownish-black coal that forms the lowest level of the coal family. You can even see the texture of the original wood in some pieces of lignite that is found west of the Mississippi River in the United States.
- **Subbituminous:** Next up the scale is subbituminous coal, a dull black coal. It gives off a little more energy (heat) than lignite when it burns. It is mined mostly in Montana, Wyoming, and a few other western states.
- **Bituminous:** Still more energy is packed into bituminous coal, sometimes called "soft coal." In the United States, 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:** Anthracite is the hardest coal and gives off a great amount of heat when it burns. Unfortunately, in the United States, as elsewhere in the world, there is little anthracite coal to be mined. The U.S. reserves of anthracite are located primarily in Pennsylvania.

Coal is not only our most abundant fossil fuel, it is also the one with perhaps the longest history.

A BRIEF HISTORY OF COAL

Coal is the most plentiful fuel in the fossil family and it has the longest and, perhaps, the most varied history. Coal has been used for heating since the cave man. Archeologists have also found evidence that the Romans in England used it in the second and third centuries (100 – 200 AD).

In the 1700s, the English found that coal could produce a fuel that burned cleaner and hotter than wood charcoal. However, it was the overwhelming need for energy to run the new technologies invented during the **Industrial Revolution** that provided the real opportunity for coal to fill its first role as a dominant worldwide supplier of energy.

During the 1300s in North America, the Hopi Indians used coal for cooking, heating, and to bake the pottery they made from clay. Coal was later rediscovered in the United States by explorers in 1673. However, commercial coal mines did not start operation until the 1740s in Virginia.

The Industrial Revolution played a major role in expanding the use of coal. A man named James Watt invented the steam engine which made it possible for machines to do work previously done by humans and animals. Mr. Watt used coal to make the steam to run his engine.

During the first half of the 1800s, the Industrial Revolution spread to the United States. Steamships and steam-powered railroads were becoming the chief forms of transportation, and they used coal to fuel their boilers.

In the second half of the 1800s, more uses for coal were found.

During the Civil War, weapons factories were beginning to use coal. By 1875, coke (which is made from coal) replaced charcoal as the primary fuel for iron blast furnaces to make steel.

Vintage Steam Locomotive

Trains were powered by steam from the mid 19th century until the mid 20th century.

The burning of coal to generate electricity is a relative newcomer in the long history of this fossil fuel. It was in the 1880s when coal was first used to generate electricity for homes and factories. By 1961, coal had become the major fuel used to generate electricity in the United States.

Long after homes were being lighted by electricity produced by coal, many of them continued to have furnaces for heating and some had stoves for cooking that were fueled by coal.

Today we use a lot of coal, primarily because we have a lot of it and we know where it is in the United States.

COAL MINING AND TRANSPORTATION

In the centuries since early humans learned that the black rocks they picked up on the ground would burn, we have had to look for coal that was hidden below the earth's surface. One of the areas it was easiest to find was where it appeared as one of many layers of materials along the side of a hill.

Then we found we could follow the coal layer (**seam**) deeper and deeper into the ground. Some mining sites today in the United States may be close to 1,000 feet underground.

Mining is classified by the method needed to reach the coal seam. When the coal is found close to the ground and taking away the overlying layers of material is not too expensive, **surface mining** is used to remove the top layers of materials and expose the coal. Today, all surface mines are reclaimed and restored to their original contours, or general appearance.

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 40 percent of U.S. coal today.

The type of **underground mining** 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.

In the mine, coal is loaded in small coal cars or on conveyor belts which carry it outside the mine to where the larger chunks of coal are loaded into trucks that take it to be crushed (smaller pieces of coal are easier to ship, clean, and burn).

The crushed coal can then be sent by truck, ship, railroad, or barge. You may be surprised to know that coal can also be shipped by pipeline. Crushed coal can be mixed with oil or water (the mixture is called a **slurry**) and sent by pipeline to a power plant or industrial user.

COAL'S ROLE IN OUR ELECTRICAL SUPPLY

In terms of supply, coal has a clear advantage over the other common source of electricity, natural gas. The United States has nearly 300 billion tons of recoverable coal. That is enough to last more than 250 years if we continue to use coal at the same rate as we use it today. In addition, coal is a versatile fuel. It can be used as a solid fuel or it can be converted to a gas to replace expensive imported fuels.

But what about costs? The mining, transportation, electricity generation, and pollution-control costs associated with using coal are increasing, but both natural gas and oil are becoming more expensive to use as well. This is, in part, because the United States must import much of its oil supply from other countries. It has enough coal, however, to take care of its electricity needs, with enough left over to export some coal as well.

The cost of using coal should continue to be even more competitive, compared with the rising cost of other fuels. In fact, generating electricity from coal is cheaper than the cost of producing electricity from natural gas. In the United States, the majority of electric power plants with the lowest operating costs use coal. Inexpensive electricity, such as that generated by coal, means lower operating costs for businesses and for homeowners. This advantage can help increase coal's competitiveness in the marketplace.

CLEANING UP COAL

Coal is our most abundant fossil fuel. The United States has more coal than the rest of the world has oil.

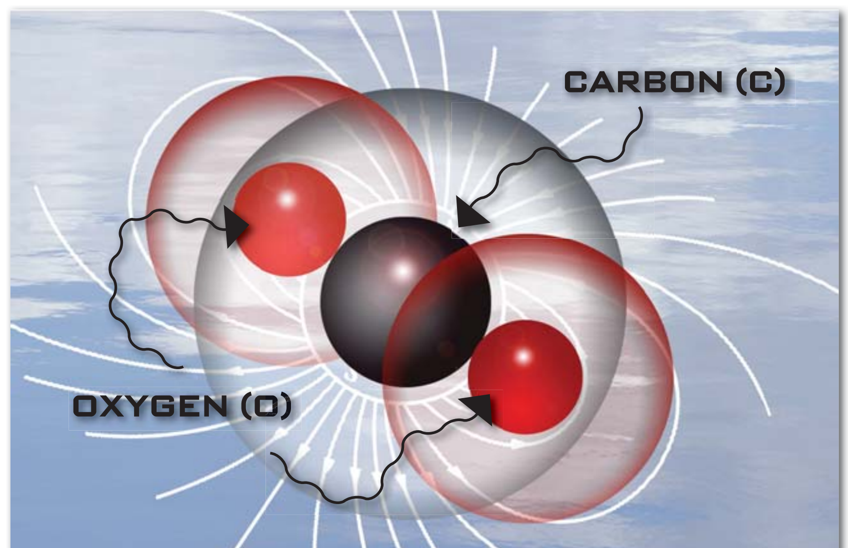
But coal is not a perfect fuel.

Trapped inside coal are traces of impurities like sulfur and nitrogen. When coal burns, these impurities are released into the air.

While floating in the air, these substances can combine with water vapor (for example, in clouds) and form droplets that fall to earth as weak forms of sulfuric and nitric acid – scientists call it "**acid rain**."

There are also tiny specks of minerals—including common dirt—mixed in coal. These tiny particles don't burn and make up the ash left behind in a coal combustor. Some of the tiny 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. Some of these particles are so small that 30 of them laid side-by-side would barely equal the width of a human hair!

Also, coal like all fossil fuels is formed out of carbon. All living things — even people—are made up of carbon. (Remember—coal started out as living plants.) 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.



Carbon Dioxide (CO_2)

is a colorless, odorless gas that is made when one Carbon (C) atom attaches to two Oxygen (O) atoms.

Many scientists believe this is causing the earth's temperature to rise, and this warming could be altering the earth's climate.

Sounds like coal is a dirty fuel to burn. Many years ago, it was. But things have changed. Especially in the last 20 years, scientists have developed ways to capture the pollutants trapped in coal before the impurities can escape into the atmosphere. Today, we have technology that can filter out 99 percent of the tiny particles and remove more than 95 percent of the acid rain pollutants in coal.

We also have new technologies that reduce the release of CO_2 by burning coal more efficiently. Scientists are also exploring techniques to capture CO_2 from power plants and store it safely underground, preventing the CO_2 from entering the atmosphere.

Many of these technologies belong to a family of energy systems called "**clean coal technologies**." Since the mid-1980s, the U.S. Government has invested more than $3 billion in developing and testing these processes in power plants and factories around the country. Private companies and State governments have been part of this program. In fact, they have contributed several billion dollars to these projects.

THE CLEAN COAL TECHNOLOGY PROGRAM

The Clean Coal Technology Program began in 1986 when the United States and Canada decided that something had to be done about the "acid rain" that was believed to be damaging rivers, lakes, forests, and buildings in both countries. Since many of the pollutants that formed "acid rain" were coming from big coal-burning power plants in the United States, the U.S. Government took the lead in finding a solution.

One of the steps taken by the U.S. Department of Energy was to create a partnership program between the government, several states, and private companies to test new methods developed by scientists to make coal burning much cleaner. This became the "Clean Coal Technology Program."

How do you make coal cleaner?

Actually there are several ways.

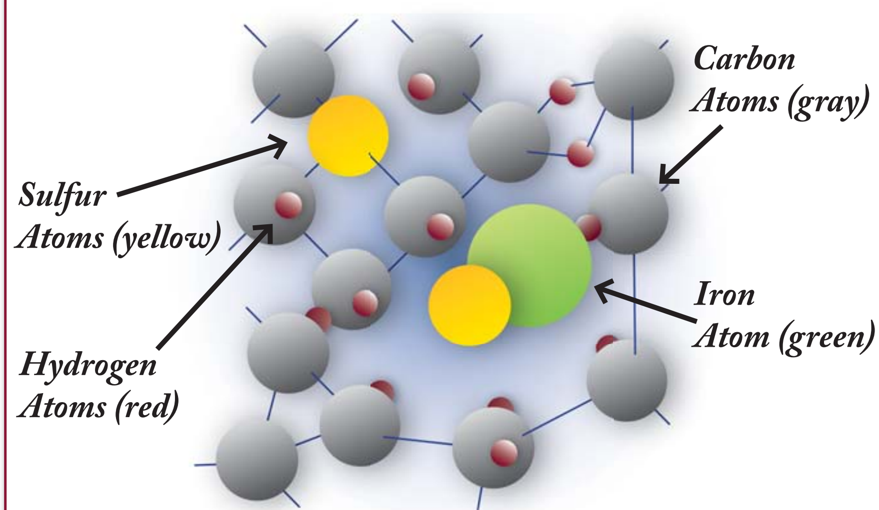
Take sulfur, for example. **Sulfur** is a yellowish substance that exists in tiny amounts in coal. In some coals found in Ohio, Pennsylvania, West Virginia, and other eastern states, sulfur makes up from 3 to 10 percent of the weight of coal.

For some coals found in Wyoming, Montana, and other western states (as well as some places in the East), the sulfur may be only 1/100ths (or less than one percent) of the weight of the coal. Still, it is important that most of this sulfur be removed before it goes up a power plant's smokestack.

Although coal is primarily a mixture of carbon (black) and hydrogen (red) atoms, sulfur atoms (yellow) are also trapped in coal, primarily in two forms. In one form, the sulfur is a separate particle often linked with iron (green) with no connection to the carbon atoms, as in the center of the drawing. In the second form, sulfur is chemically bound to the carbon atoms, such as in the upper left.

Coal

is primarily made up of Carbon, Sulfur, Hydrogen, and Iron



One way is to clean the coal before it arrives at the power plant. One of the ways this is done is by simply crushing the coal into small chunks and washing it. Some of the sulfur that exists in tiny specks in coal (called "pyritic sulfur" because it is combined with iron to form iron pyrite, otherwise known as "fool's gold") can be washed out of the coal in this manner. Typically, in one washing process, the coal chunks are fed into a large water-filled tank. The coal floats to the surface while the sulfur impurities sink. There are facilities around the country called "**coal preparation plants**" that clean coal this way.

Not all of coal's sulfur can be removed like this, however. Some of the sulfur in coal is actually chemically connected to coal's carbon molecules instead of existing as separate particles. This type of sulfur is called "**organic sulfur**," and washing won't remove it. Several processes have been tested to mix the coal with chemicals that break the sulfur away from the coal molecules, but most of these processes have proven too expensive. Scientists are still working to reduce the cost of these chemical cleaning processes.

Most modern power plants—and all plants built after 1978—are required to have special devices installed that clean the sulfur from the coal's combustion gases before the gases go up the smokestack. The technical name for these devices is "**flue gas desulfurization units**," but most people just call them "**scrubbers**"—because they "scrub" the sulfur out of the smoke released by coal-burning boilers.

How do scrubbers work?

Most scrubbers rely on a very common substance found in nature called "**limestone**." We literally have mountains of limestone throughout this country. When crushed and processed, limestone can be made into a white powder. Limestone can be made to absorb sulfur gases under the right conditions—much like a sponge absorbs water.

In most scrubbers, limestone (or another similar material called lime) is mixed with water and sprayed into the coal combustion exhaust gases (called "**flue gases**"). The limestone captures the sulfur and "pulls" it out of the gases. The limestone and sulfur combine with each other to form either a wet paste (it looks like toothpaste!), or in some newer scrubbers, a dry powder. In either case, the sulfur is trapped and prevented from escaping into the air.

The Clean Coal Technology Program tested several new types of scrubbers that proved to be more effective, lower cost, and more reliable than older scrubbers. The program also tested other types of devices that sprayed limestone inside the tubing (or "ductwork") of a power plant to absorb sulfur pollutants.

But what about nitrogen pollutants? That's another part of the Clean Coal story.

Drywall, or Gypsum Board

is what is used to construct the inside walls of buildings. A drywall panel is made of gypsum. Gypsum is a very soft mineral composed of calcium sulfate dihydrate and is made when flue gases are cleaned.

KNOCKING THE NOx OUT OF COAL

Nitrogen is the most common part of the air we breathe. In fact, about 80 percent of the air is nitrogen. Normally, nitrogen atoms float around joined to each other like chemical couples. But when air is heated—in a coal boiler's flame, for example—these nitrogen atoms break apart and join with oxygen. This forms "**nitrogen oxides**"—or, as it is sometimes called, "**NOx**" (rhymes with "socks"). NOx can also be formed from the atoms of nitrogen that are trapped inside coal.

In the air, NOx is a pollutant. It can cause smog, the brown haze you sometimes see around big cities. It is also one of the pollutants that forms "**acid rain**." And it can help form something called "**groundlevel ozone**," another type of pollutant that can make the air dingy.

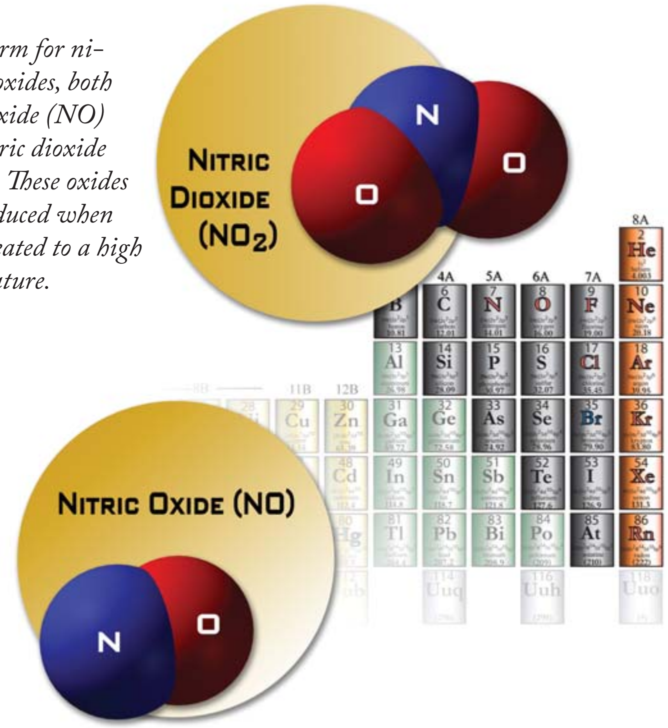
NOx can be produced by any fuel that burns hot enough. Automobiles, for example, produce NOx when they burn gasoline. But a lot of NOx comes from coal-burning power plants, so the Clean Coal Technology Program developed new ways to reduce this pollutant.

One of the best ways to reduce NOx is to prevent it from forming in the first place. Scientists have found ways to burn coal (and other fuels) in burners where there is more fuel than air in the hottest combustion chambers. Under these conditions, most of the oxygen in air combines with the fuel, rather than with the nitrogen. The burning mixture is then sent into a second combustion chamber where a similar process is repeated until all the fuel is burned.

This concept is called "**staged combustion**" because coal is burned in stages. A new family of coal burners called "**low-NOx burners**" has been developed using this way of burning coal. These burners can reduce the amount of NOx released into the air by more than half. Today, because of research and the Clean Coal Technology Program, approximately 75 percent of all the large coal-burning boilers in the United States use these types of burners.

NOx

is the term for nitrogen oxides, both nitric oxide (NO) and nitric dioxide (NO_2). These oxides are produced when air is heated to a high temperature.



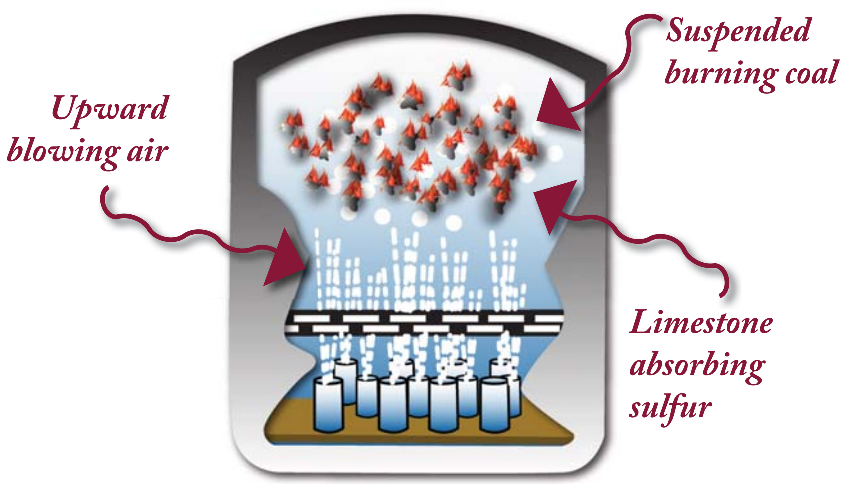
There is also a family of new technologies that work like scrubbers by cleaning NOx from the flue gases (the smoke) of coal burners. Some of these devices use special chemicals called "**catalysts**" that break apart the NOx into non-polluting gases. Although these devices are more expensive than "low-NOx burners," they can remove up to 90 percent of NOx pollutants.

But in the future, there may be an even cleaner way to burn coal in a power plant. Or maybe there may be a way that doesn't burn the coal at all.

A BED FOR BURNING COAL?

In 1979, a few scientists and engineers joined with government and college officials on the campus of Georgetown University in Washington, D.C. to celebrate the completion of one of the world's most advanced coal combustors. It was a small coal burner by today's standards, but large enough to provide heat and steam for much of the university campus. This was the birth of the "**fluidized bed boiler**."

In a typical coal boiler, coal would be crushed into very fine particles, blown into the boiler, and ignited to form a long, lazy flame. Or in other types of boilers, the burning coal would rest on grates. But in a "fluidized bed boiler," crushed coal particles float inside the boiler, suspended on upward-blowing jets of air. The red-hot mass of floating coal—called the "bed"—would bubble and tumble around like boiling lava inside a volcano. Scientists call this being "fluidized."



A Fluidized Bed Boiler

In a fluidized bed boiler, upward blowing jets of air suspend burning coal, allowing it to mix with limestone that absorbs sulfur pollutants.

Why does a "fluidized bed boiler" burn coal cleaner?

There are two major reasons. One, the tumbling action allows limestone to be mixed in with the coal. (Remember—limestone absorbs sulfur pollutants.) As coal burns in a fluidized bed boiler, it releases sulfur. But just as rapidly, the limestone captures the sulfur. A chemical reaction occurs, and the sulfur gases are changed into a dry powder that can be removed from the boiler. (This dry powder—called **calcium sulfate**—can be processed into the wallboard we use for building walls inside our houses.) The second reason a fluidized bed boiler burns cleaner is that it burns "cooler." Now, cooler in this sense is still pretty hot—about 1400 degrees F. But older coal boilers operate at temperatures nearly twice that (almost 3000 degrees F).

Remember NOx from the page before? NOx forms when a fuel burns hot enough to break apart nitrogen molecules in the air and cause the nitrogen atoms to join with oxygen atoms. But 1400 degrees isn't hot enough for that to happen, so very little NOx forms. The result is that a fluidized bed boiler can burn very dirty coal and remove 90 percent or more of the sulfur and nitrogen pollutants while the coal is burning.

Today, fluidized bed boilers are operating or being built that are 10 to 20 times larger than the small unit built almost 20 years ago at Georgetown University. There are more than 300 of these boilers around this country and the world. The Clean Coal Technology Program helped test these boilers in Colorado, in Ohio and most recently, in Florida.

Now a new type of fluidized bed boiler—the "**pressurized fluidized bed boiler**"—is expanding the original technology to the point that it is becoming more and more efficient. In fact, future boilers using this system will be able to generate 50 percent more electricity from coal than a regular power plant from the same amount of coal—and it will reduce the amount of carbon dioxide (a greenhouse gas) released from coal-burning power plants. So, pressurized fluidized bed boilers are one of the newest ways to burn coal cleanly. But there is another new way that doesn't actually burn the coal at all.

THE CLEANEST COAL TECHNOLOGY—A REAL GAS!

Don't think of coal as a solid black rock. Think of it as a mass of atoms. Most of the atoms are carbon. A few are hydrogen. And there are some others, like sulfur and nitrogen, mixed in. Chemists can take this mass of atoms, break it apart, and make new substances—like gas!

How do you break apart the atoms of coal? You may think it would take a sledgehammer, but actually all it takes is water and heat. Heat coal hot enough inside a big metal vessel, blast it with steam (the water), and it breaks apart. Into what?

The carbon atoms join with oxygen that is in the air (or pure oxygen can be injected into the vessel). The hydrogen atoms join with each other. The result is a mixture of carbon monoxide and hydrogen—a gas.

Now, what do you do with the gas?

You can burn it and use the hot combustion gases to spin a gas turbine to generate electricity. The exhaust gases coming out of the gas turbine are hot enough to boil water to make steam that can spin another type of turbine to generate even more electricity. But why go to all the trouble to turn the coal into gas if all you are going to do is burn it?

A major reason is that the impurities in coal—like sulfur, nitrogen, and many other trace elements—can be almost entirely filtered out when coal is changed into a gas (a process called **gasification**). In fact, scientists have ways to remove 99.9 percent of the sulfur and small dirt particles from the coal gas. Gasifying coal is one of the best ways to clean pollutants out of coal.

Another reason is that the coal gases—**carbon monoxide and hydrogen**—don't have to be burned. They can also 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!

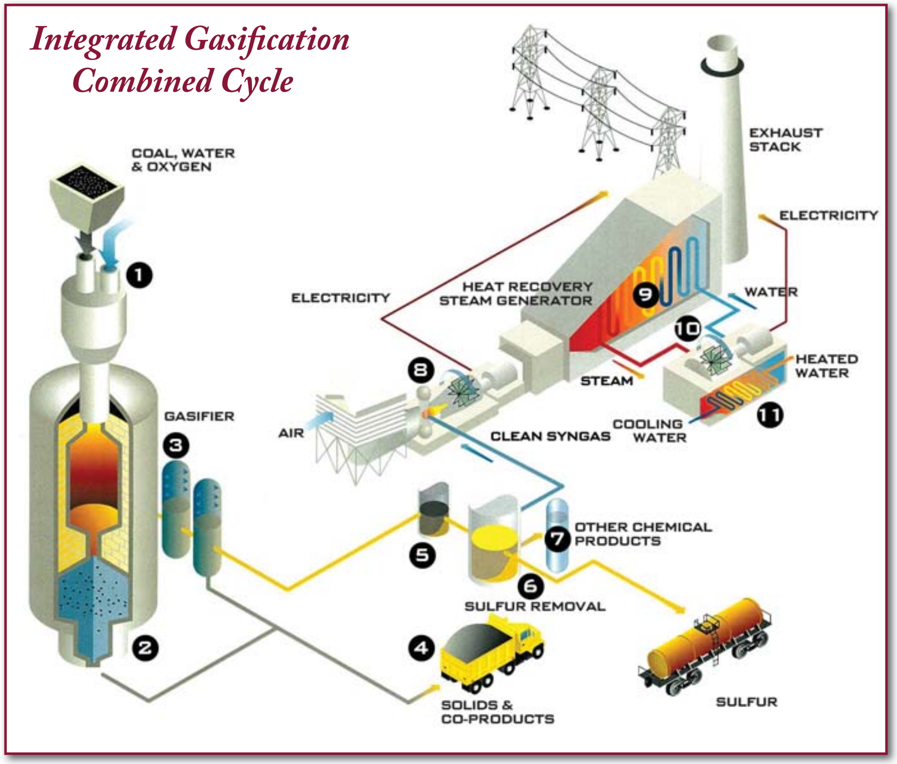
Tampa Electric's Polk Power Station

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.

Today, outside of Tampa, Florida (near the town of Lakeland), and in West Terre Haute, Indiana, there are power plants generating electricity by gasifying coal, rather than burning it. At a plant in Kingsport, Tennessee, coal gas is being used to make plastic for photographic film and to make methanol (a fuel that can be burned in automobile engines).

Coal gasification could be one of the most promising ways to use coal in the future to generate electricity and other valuable products. Yet, it is only one of an entirely new family of energy processes called "Clean Coal Technologies"—technologies that can make fossil fuels, future fuels.

A coal gasification power plant 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—more than at conventional coal-based boiler plants.



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

COAL AND CLIMATE CHANGE

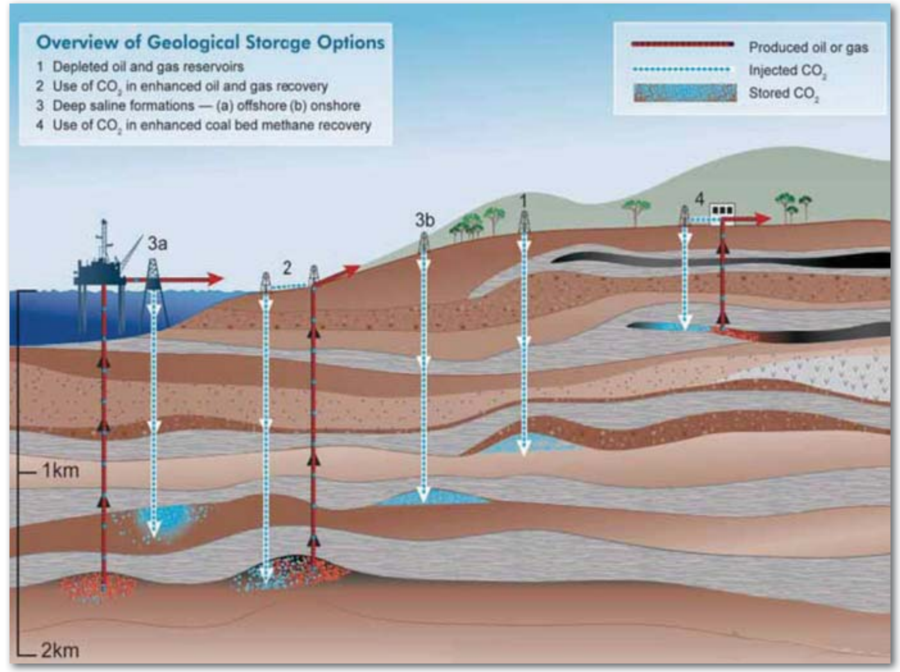
When we address climate change, we can't ignore coal. It is expected that coal and other fossil fuels will remain a major energy source for years to come. So the question becomes, how can we continue to use coal so that it doesn't release carbon dioxide into the air?

Scientists have been studying ways to capture CO_2 from coal-fired power plants before it is released into the air. The CO_2 would then be transported and eventually injected underground in deep geologic formations (such as old oil fields, saline aquifers, and unmineable coal seams), where it would be stored for a long, long time. Scientists are even studying ways to recycle the CO_2 into new materials. The technical name for this process is "**carbon capture and storage**," or "**carbon sequestration**."

The best reservoirs for CO_2 storage are depleted oil and gas fields and deep saline formations. These are layers of porous rock (such as **sandstone**) nearly a mile underground (either on land or far below the sea floor), located underneath a layer of impermeable rock (known as a **cap-rock**) which acts as a seal.

In the case of oil and gas fields, it was this cap-rock that trapped the oil and gas underground for millions of years. Depleted oil and gas fields are the best places to start storing CO_2 because their geology is well known and they are proven traps. CO_2 has been injected into old (often referred to as "**declining**" or "**depleted**") oil fields for more than 30 years, to increase oil recovery.

Deep saline formations are rocks with pore spaces that are filled with very salty water (much saltier than seawater). They exist in most regions of the world and appear to have a very large capacity for CO_2 storage. Currently the geology of saline formations is less well understood than for oil and gas fields so more work needs to be done to understand which formations will be best suited to CO_2 storage.



Scientists continue to research and develop carbon sequestration technologies that are reliable and less expensive than today's technologies. It is important to make sure these new processes are environmentally acceptable and safe. For example, science must determine that CO_2 will not escape from under the ground, or contaminate drinking water supplies. Carbon capture and storage is a promising area of climate change research and development.