U.S. DEPARTMENT OF ENERGY

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, just over 1/4 of all the known coal in the world is in the United States. The United States has more coal that can be mined than the rest of the world has oil that can be pumped from the ground.

Currently, coal is mined in 26 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 more than 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 primarily 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. If you are interested in the early discovery and uses of coal...

A Brief History of Coal Use

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 1800s, one of the primary uses of coal was to fuel steam engines used to power locomotives.

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.

In North American, the Hopi Indians during the 1300s in what is now the U.S. Southwest 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.

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.

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

One type of mining, called "longwall mining", uses a rotating blade to shear coal away from the underground seam.

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 below 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 500 feet underground.

Mining is classified by the method needed to reach the coal seam. When the coal is found close to the Earth's crust 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.

If coal is found in layers far from the surface, underground mining is the preferred technique. Vertical or slanted holes ("shafts") are cut down to the mining area underground for ventilation for the workers and

for transporting the miners, equipment, and coal. Common types of underground mining are the drift, shaft, and slope mining methods.

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, burn, etc.).

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 an industrial user.

COAL is our most abundant fossil fuel. The United States has more coal than the rest of the world has oil. There is still enough coal underground in this country to provide energy for the next 200 to 300 years.

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 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 (read more about the "greenhouse effect").

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 cut back on 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." 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 more than several billion dollars to these projects.

The Clean Coal Technology Program

The Clean Coal Technology Program began in 1985 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."

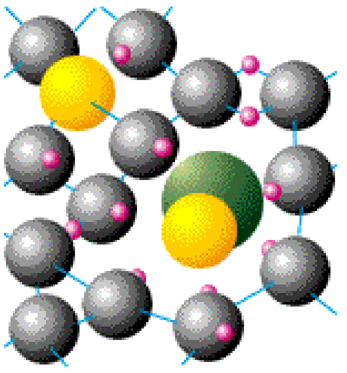
How do you make coal cleaner?

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 can be only 1/100ths (or less than 1 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.

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.



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.

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 process 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 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.

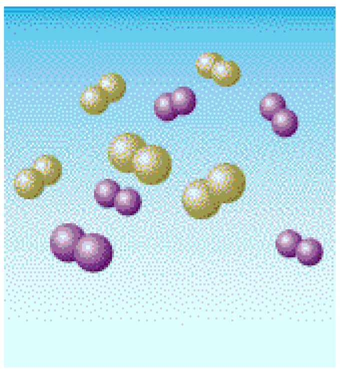
The Clean Coal Technology Program tested several new types of scrubbers that proved to be more effective, lower cost, and more reliable than older scrubbers. The program also tested other types of

devices that sprayed limestone inside the tubing (or "ductwork') of a power plant to absorb sulfur pollutants.

Knocking the NOx Out of Coal

Nitrogen is the most common part of the air we breathe. In fact, about 80% 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.

How NOx Forms



Air is mostly nitrogen molecules (green in the above diagram) and oxygen molecules (purple). When heated hot enough (around 3000 degrees F), the molecules break apart and oxygen atoms link with the nitrogen atoms to form NOx, an air pollutant.

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 will be using these types of burners.

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.

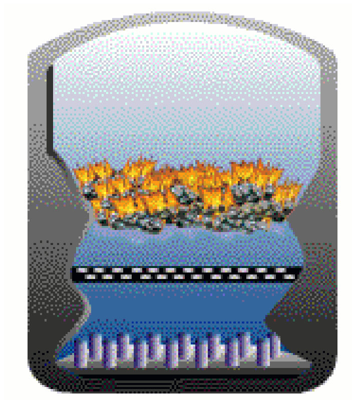
A "Bed" for Burning Coal?

It was a wet, chilly day in Washington DC in 1979 when a few scientists and engineers joined with government and college officials on the campus of Georgetown University 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. But the new boiler built beside the campus tennis courts was unlike most other boilers in the world.

It was called a "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." That's how the name "fluidized bed boiler" came about.

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 from a couple of pages ago. Limestone is a sulfur sponge — it absorbs sulfur pollutants. As coal burns in a fluidized bed boiler, it releases sulfur. But just as rapidly, the limestone tumbling around beside the coal 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 in a fluidized bed boiler.

The result is that a fluidized bed boiler can burn very dirty coal and remove 90% or more of the sulfur and nitrogen pollutants while the coal is burning. Fluidized bed boilers can also burn just about anything else — wood, ground-up railroad ties, even soggy coffee grounds.

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.

The Ohio Power Company built this advanced pressurized fluidized bed boiler near the town of Brilliant, OH, as part of a joint project with the U.S. Department of Energy.

A new type of fluidized bed boiler makes a major improvement in the basic system. It encases the entire boiler inside a large pressure vessel, much like the pressure cooker used in homes for canning fruits and vegetables — except the ones used in power plants are the size of a small house!

Burning coal in a "pressurized fluidized bed boiler" produces a high-pressure stream of combustion gases that can spin a gas turbine to make electricity, then boil water for a steam turbine — two sources of electricity from the same fuel!

A "pressurized fluidized bed boiler" is a more efficient way to burn coal. In fact, future boilers using this system will be able to generate 50% more electricity from coal than a regular power plant from the same amount of coal. That's like getting 3 units of power when you used to get only 2.

Because it uses less fuel to produce the same amount of power, a more efficient "pressurized fluidized bed boiler" will reduce the amount of carbon dioxide (a greenhouse gas) released from coal-burning power plants.

"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?

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.

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 uses 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% 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!

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.

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.