Energy Efficiency Design

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On the Grid

Soung-Sik Kim

Courtesy of Soung-Sik Kim

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We have a lot of coal in the United States. According to current estimates, we won't run out of coal for another two hundred years or so. Coal is used in a variety of ways for home heating and alternative transportation fuels, but most of the coal mined today is used for generating electricity. Because it's relatively inexpensive, coal will continue to be the most widely used fuel for electric power generation for quite a while. The goal of clean coal research is to find ways to use coal more efficiently, with less pollution, and with a lower cost.

That's what my work is all about. I'm Soung-Sik Kim, a senior project manager at the National Energy Technology Laboratory (NETL). NETL is a part of the United States Department of Energy, which is the government agency that oversees America's energy use. I work on programs related to clean-coal research, but I wasn't always interested in coal.

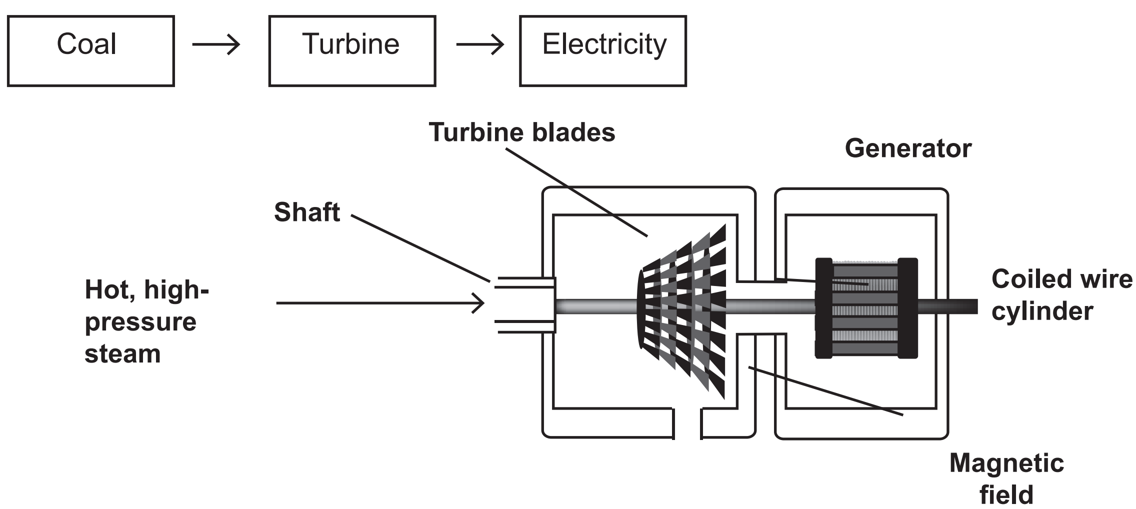
When I was a ninth grader at an all-girls' high school in Seoul, South Korea, there was a national contest in which students competed by taking exams in mathematics and science. I won. From that moment on, I started dreaming of becoming a famous scientist like Madam Curie, who worked on radioactivity in the early 1900s. My father encouraged me to go into engineering because I was always playing with numbers and I liked science. I didn't really know what engineering was all about, but I decided to study chemical engineering because it was the most competitive field of study in Korea at that time. I've always liked a challenge!

When I went to graduate school for chemical engineering, I started studying coal. For my Master's thesis, I measured how fast coal burns or reacts with other chemicals. My Doctoral thesis was about optimizing part of a coal gasification process, which is a very efficient way to release the energy in coal. Four decades later, I am still in the coal business!

Today, about 90 percent of the coal mined in the United States is used for generating electricity. Approximately half of the electricity we use comes from coal-fired power plants. Other countries that do not have large coal reserves use natural gas, oil, nuclear power, or hydroelectric power (waterfalls). We are lucky to have so much coal to produce low-cost, reliable electricity.

In a coal-fired power plant, producing electricity begins with burning coal to heat up water in a boiler. The water boils, becoming steam. The hot steam flows toward the cooler side of the turbine, causing the turbine blade to spin in much the same way as when the blades of a pinwheel spin when you blow on them. The turning blades of the turbine spin a shaft that is connected to an electrical generator. Inside the generator, a rod wrapped with a wire coil spins inside a housing containing large magnets, which generates electricity. So the energy of the coal has been transferred to moving electrical charge.

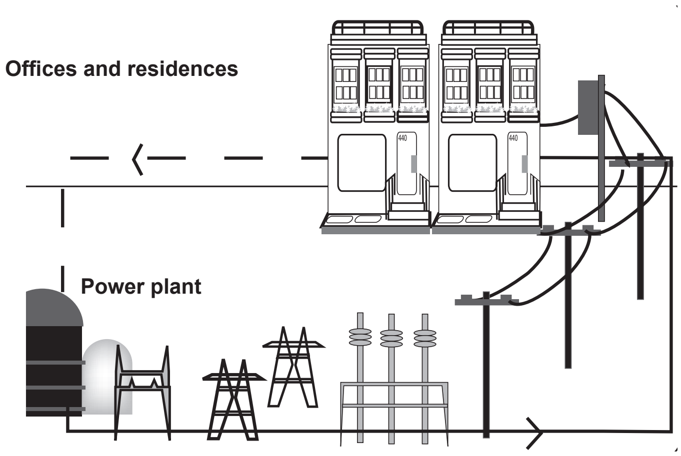
Inside the Turbine



On the Grid

Whether a power plant produces electricity from oil, natural gas, nuclear, or from coal plants like the kind Soung redesigns, all power plants feed the electricity they produce directly into a power distribution grid. The grid is a huge network of power stations, distribution stations, and wiring that brings electrical power to users—homes, schools, and office buildings.

The grid is really a complex system of circuits. Each electrical circuit is a closed continuous conducting loop. The illustration below shows a very simplified circuit on the grid. The power plant acts as an energy source, pushing charge around the circuit. The moving charge carries energy to do work—wash dishes, light a hallway, dry hair, you name it.



The electric wires or lines you see every day carry the electrical charge from the power plant to the homes, schools, and businesses. But, unlike a battery or the electric plug in your house that has a return line to complete the circuit, power plants use the Earth itself to complete the power circuit. Often called a "ground" or the "ground return," the Earth is an excellent conductor because it eliminates the need for a return line to the load. In order to use the Earth as a ground, the return wire at the power plant and at your house, for example, is connected to a metal rod or stake that is hammered into the ground.

The grid from which your home or school draws its power is quite extensive. There are ten grids in North America, each serving tens of millions of people. Private power plants, the majority of which burn coal or other fossil fuels, add to the supply of electricity on the grid. Power companies provide grid access to the end-users. The power companies are responsible for ensuring that enough electrical power is available on the grid to meet their users' needs 24 hours a day.

Power
is the rate at which energy is consumed or produced. It is measured in watts.

1 megawatt = 1,000,000 watts
1 kilowatt = 1,000 watts

Energy
in electricity is often measured in kilowatt-hours.

1 kilowatt-hour =
1 kilowatt consumed in an hour

Efficiency
is defined as the ratio of useful energy outputs to energy inputs in a system.

It is expressed as a percentage.

Thus, 100 percent efficiency in a power plant means all of the energy is transferred to electricity.

A Question of Efficiency

One of the main goals of my work is to increase the efficiency of coal-fired power plants. In a coal-fired power plant, the input is coal; the output is electric power. What's power? You learned that power is the rate at which work is done per unit time, expressed in joules per second, or watts.

A typical coal-fired power plant produces 500–1,000 megawatts of electrical power. A megawatt is equal to 1,000,000 watts. (A kilowatt is equal to 1,000 watts.)

It takes a lot of coal to produce this much power. As you know, coal contains stored energy—about 28,000,000 BTUs per ton. If a coal-fired power plant were 100 percent efficient, then all of the energy in the coal it burns would be transferred to the electricity.

While power plant output is measured in megawatts or kilowatts, engineers often measure the energy in electricity in kilowatt-hours. A kilowatt-hour (kWh) is the number of kilowatts consumed in one hour of time. If one ton of coal were burned in a perfect plant, the energy output would be about 8,235 kWh (3,400 BTU ≈ 1 kWh). However, due to many energy losses in a power plant when producing electricity, a typical coal-fired plant is only about 33 percent efficient.

Where is the energy lost in the power plant? Some of the energy released from burning the coal gets transferred from the boiler to the surrounding air. More energy is transferred to the rod that spins the coils of wire, heating it up. Energy is also needed to move coal around in the plant and pump water into the boiler.

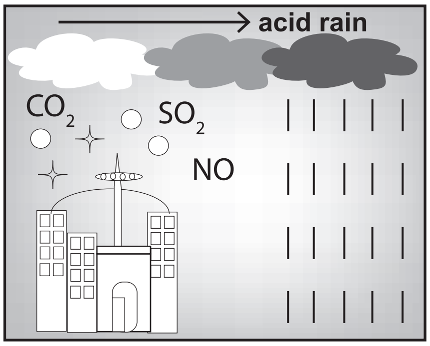
In a plant running at 33 percent efficiency, the actual coal input must be over three tons for every 10,000 kWh of output. Just to put this in perspective, the average American household consumes about 8,900 kWh of energy delivered by electricity each year. It takes over three tons of coal to generate that much!

My research in making coal plants more efficient will allow us to burn less coal to meet our electrical needs. And because we will be burning less coal, we'll produce less pollution and keep costs lower.

One power plant we're working on in Illinois is an excellent example of how we're trying to increase the efficiency of coal-fired plants. We're retrofitting the plant with a feedback control system that uses sensors to monitor the temperature of gases in the combustion chamber. The sensors provide feedback to a computerized control system that constantly adjusts the flame size or the oxygen level in the chamber so that the burning coal transfers as much energy as possible to the water in the boiler and reduces nitrogen oxides. Without such a system, the size of the furnace flame and the amount of air let into the furnace must be controlled manually. Letting a computer handle the controls—with feedback from sensors—cuts down on human error and optimizes furnace efficiency.

In the same plant, we've installed a computerized sootblower system to improve efficiency. As I said before, burning coal produces a lot of soot and ash. The soot often builds up on the boiler, causing unwanted insulation, that prevents the energy released by the burning coal from reaching the water. The computerized system we're installing senses when soot is building up on the boiler and activates a machine called a sootblower, which uses steam to blow the soot off the boiler tubes. This helps increase the amount of energy that goes into heating the water, and makes the whole process more efficient.

These may seem like small adjustments, but we've learned that making a lot of these small adjustments really does add up to big increases in efficiency. For every one percent increase in efficiency, we generate 5 more megawatts of electricity in a 500-megawatt plant burning the same amount of coal. This brings costs and pollution down.



The Problems Clean Coal Research Can Solve

As with any fossil fuel, there are some problems with burning coal for electricity generation. Coal is made of mostly carbon with some sulfur and nitrogen. When coal is burned, its smoke contains carbon dioxide, sulfur dioxide, and nitrogen oxides—three gases that can lead to poor air quality. Burning coal also produces tiny pieces of ash, which can irritate people's lungs and cause smog.

The government started funding clean coal research in the 1980s in response to public outrage about high levels of sulfur dioxide and nitrogen oxide gases in our atmosphere. These gases, produced as a byproduct in coal-fired plants, combined with the water in raindrops and produced "acid rain." The acid rain had a detrimental effect on ecosystems. Clean coal research has improved methods for removing these harmful gases from the plant exhaust before they are released into the atmosphere.

The Environmental Protection Agency (EPA) now places limits on the amount of pollutants a power plant can release into the environment. The clean coal research I'm involved in helps new and old power plants reduce the emissions of "dirty" gases into the atmosphere.

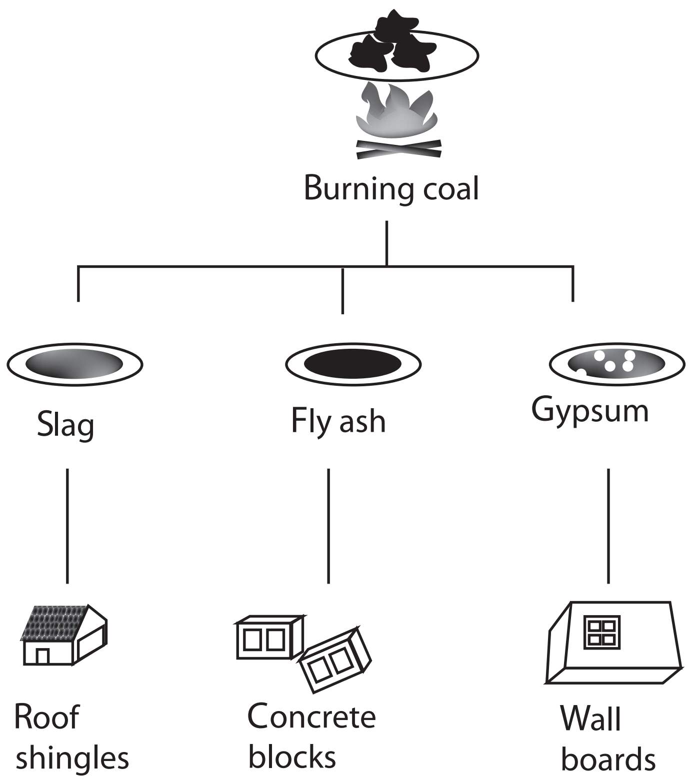
Make By-Product, Not Waste

We've also developed some pretty creative new ways to reduce the amount of waste products that enter the environment from our plants. In one project we've developed a way to burn coal at a very high temperature. This causes the ash to melt. The molten ash—a substance called "slag"—is used to make roof shingles. Maybe the shingles on your house are made from slag. We've also built a concrete-block factory next to a coal power plant in Pennsylvania. The factory uses fly ash from burning coal as an ingredient in concrete. Brilliant!

At another plant we've developed a way to clean sulfur dioxide gas out of the plant's exhaust. We run the exhaust through a "scrubber" that uses a liquid mixture of limestone. The sulfur dioxide reacts with the limestone and becomes gypsum. Gypsum is used to make wallboards for homes. So every day, new clean-coal technologies are changing the way that we produce power in this country—for the better. Through all of these efforts, our community, our country, and the world will be healthier.

Good engineering is not just about coming up with something new. It's also about improving a solution that already exists. If we keep coming up with new ideas to increase the efficiency of coal plants and to reduce pollutants, I believe we can meet our nation's energy needs using coal without importing more oil from other countries, and without sacrificing our own health and the health of our environment.

Different By-Products of Coal



What's the Story?

1. What is Soung referring to when she talks about "the grid," and how does "the grid" supply our electrical power?

2. What caused the U.S. government to start funding clean-coal research like the kind the Soung does?

3. Describe two ways that Soung is making coal-fired power plants more efficient and cleaner for the environment.

Designing with Science and Math

4. What is necessary for charge to flow through a circuit?

5. What is the relationship between energy and power? What are the units for each?

6. If two power plants each output the same amount of electricity every hour, but one requires 2 million tons of coal per year and the other requires 1.75 million tons of coal per year, which is more efficient? Explain how you know.

Connecting the Dots

7. Is any process 100 percent efficient? Why or why not? Give some examples from previous chapters to explain your response.

What Do You Think?

8. In the last paragraph of the story, Soung says, "Good engineering is not just about designing something new." What does she mean by that? Do you agree? Use an example that you've learned about in this class or outside of class to explain why or why not.

9. Go home and find out what your power company charges for each kWh of electricity. What is your average electric bill per month? How much energy does your household use per year?