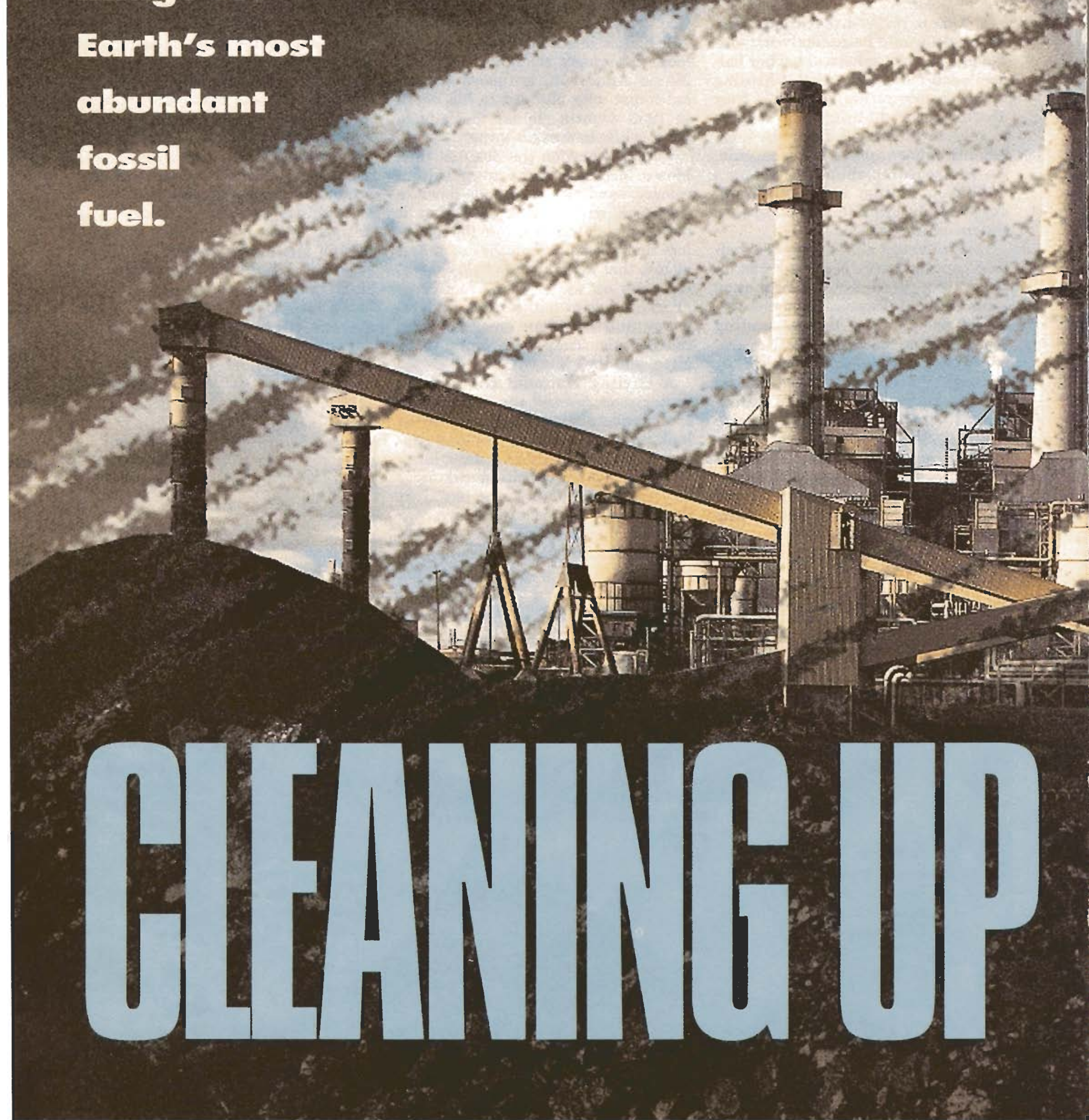
CLEANING UP

Emerging technologies could fashion a clean new image for Earth's most abundant fossil fuel.

Wayne Irons is busily dancing back and forth between diagrams of boilers on American Electric Power's new Bailey Network 90 touch-screen computer control system. Effortlessly, Irons calls up engineering drawings of the giant pressurized fluidized-bed combustor that sits some 50 yards away, a huge boiler constructed to test one promising new design for environmentally friendly coal-fired generating plants.

At first, this unlikely coupling of leading-edge electronics with a primitive heat source seems an impossible relationship, but then a striking parallel emerges: This enormous structure with the tongue-tangling name is as fundamental a change to coal-burning as the



computer display is to the sheaves of rolled-up blueprints that preceded it.

Pausing in his keyboard exercises, Irons suddenly looks up, worry in his eyes.

"You know," he tells me, "people along this part of the river ask me all the time, 'How's it going? You guys gonna build another?'

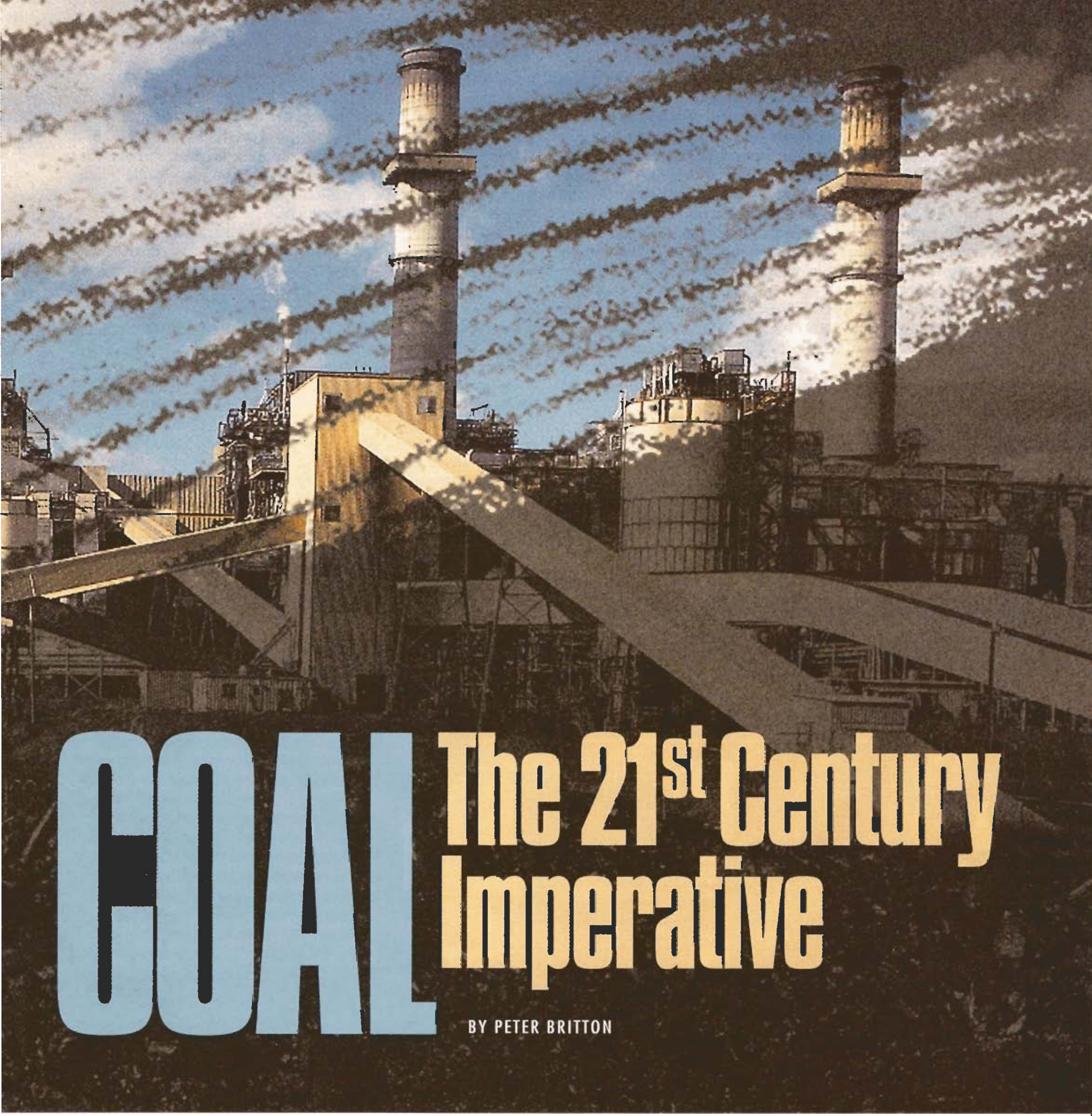
"These folks are hopeful—and scared. Coal is their past and their present. Clean coal is their future. And this project can make a real difference."

Indeed. Not only in the United States, where more than half the electric power is generated by coal-burning plants, but also in developing countries. China, for example, depends on coal for more than 75 percent of its energy needs to support a population of more than a billion people, and the possible effects on Earth's atmosphere staggers the imagination.

Swept up in Irons' enthusiasm, I follow the energetic operations superintendent as he strides toward the 70-foot-high combined-cycle pressurized fluidized-bed combustor. The $185 million hope of utilities, government, and environmentalists alike, it grandly fills a cavernous section of the American Electric Power Tidd Plant located in Brilliant, Ohio.

Irons leads us to a three-foot-diameter hatch at the base of the boiler. An avid spelunker, Irons swings himself easily inside, glorying in his element of claustrophobic and questionable spaces. I scramble behind him into a

OVAK ARSLANIAN / GAMMA LIAISON



COAL The 21st Century Imperative

BY PETER BRITTON

chamber clogged with pipes, tubes, and wires at the bottom of the boiler. This narrow space where we have ventured—between the bed vessel and the cylinder that completely surrounds it—contains a pressure of 165 pounds per square inch when the unit is operating.

I peek inside a small hatch window on the side of the boiler, and I'm confronted by a thicket of closely woven piping. On the floor of the boiler itself are sparge ducts—nozzles for injecting high-pressure air blasts that keep pulverized high-sulfur bituminous coal churning, burning, and chemically coupling its sulfur with injected limestone. This mixture of coal and limestone is suspended inside on the air jets, forming the "bed." The action, which resembles that of a boiling liquid, explains the "fluidized" terminology.

Above us are the guts of the bed and the equipment needed to siphon off the results of combustion: heat, flue gas, and ash. The 1,580°F fires will heat water in pipes, producing steam to spin turbines. In addition, the high-pressure gas exhaust flow from the unit drives a gas turbine, providing the "combined cycle" portion of the nomenclature. When fired, this demonstration unit is designed to burn 840 tons of coal a day and generate 70 megawatts of electricity.

The success of the Tidd plant has ramifications that are important to everyone, for what Irons and his colleagues are testing at Tidd is a clean-coal technology that can ultimately remove 95 percent of the sulfur dioxide (SO_2) and 80 percent of the nitrogen oxides (NO_X) from electric-utility stacks. To approach this level of cleanliness in conventional coal-fired plants, smokestack scrubbers and selective catalytic reduction normally would be required. And as one of the lead projects in the federal Department of Energy's (DOE) Clean Coal Technology Program, Irons' fiery, complex baby will also demonstrate commercial-scale feasibility of a process that produces 10 percent less carbon dioxide (CO_2) than other coal technologies for a given amount of energy produced—the result of the Tidd plant's higher operating efficiencies.

The implications of this project, along with 41 sister projects in the clean-coal joint adventure between business and industry, are profound and worldwide. They represent the future of coal as a fuel for generating electricity and could have a huge impact on the environment, for coal's present status in the world energy/environment picture is both certain and precarious.

This much is true: Coal is an abundant, cheap, and evenly distributed fuel capable of powering half the world well into the next century. In the United States, it currently generates 55 percent of domestic electricity, effectively making half of all our toasters and televisions coal-powered appliances; even the electric cars that will hit the market in coming years must, to some extent, be seen as coal-powered. Supply is plentiful: Coal represents 95 percent of the domestic fossil-fuel energy resource (a reassuring thought in terms of energy independence) and 70 percent of the world's. And while it represents a Pandora's box of regulatory, pricing, and environmental headaches (SO_2, NO_X, CO_2, and particulates, et al.) whose complexity has no equal, it also offers the potential for a bonanza of new technologies that industrialized countries can export to developing countries over the next 20 years.

Of course, "clean" in conjunction with coal is a relative term. Back in 1900, when a West Virginia coal miner could load 16 tons in ten hours and get another day older and deeper in debt, those 32,000 pounds of high-sulfur bituminous burned in the unsophisticated furnaces of the era wreaked awesome havoc on the environment: 2,880 pounds of sulfur dioxide (the acid rain instigator), 3,200 pounds of nitrogen oxides, 82,208 pounds of carbon dioxide, various trace metals, culm bank fires, sludge, toxic leachings, clinkers (lumps of mineral impurities that fuse together when coal is burned), acid rain, and smoke. And all of this for the prized 384 million Btu of heat, or the equivalent of 16 cords of firewood. Today's long-wall mining machine can shear the same 16 tons from a seam of coal in as little as 30 seconds. And while the modern miner still gets another day older and deeper in debt, his product goes through increasingly complicated processes that are inching dirty old coal to a new and "clean" respectability.

Compared with past emissions, coal today can be up to 99.9 percent cleaner with regard to sulfurs and, to a lesser degree, with regard to nitrogen oxides and particulates. But, save for improved efficiencies that require less coal for the same energy output, carbon dioxide emissions from coal-fired power plants remain the same: appalling. No wonder coal is the fuel that environmentalists love to hate most. Still, some have come to accept coal as necessary to bridge the gap from the present to an energy future that includes solar, wind, geothermal, synthetic fuels, natural gas, fuel cells, and nuclear fusion.

PRECOMBUSTION CLEANUP: EXPERT ADVICE, BY COMPUTER

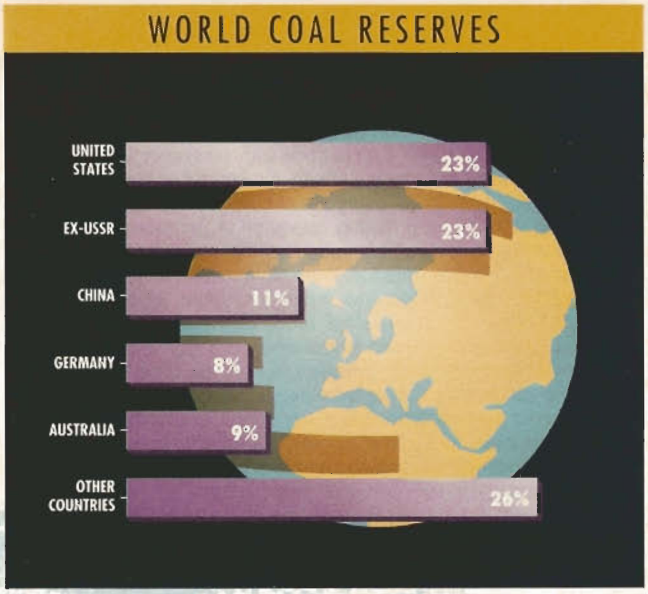
The Coal Quality Expert from CQ, Inc. of Homer City, Pa., aims to clean up smokestack gases at the earliest possible stage—the fuel source. Field tests, consisting of trial burns at bench-, pilot-, and full-scale operation, are being used to develop algorithms that will help power plant operators predict pollutant levels based on several alternative qualities of coal from different sources. Using this program, coal-fired utilities will then be able to select the optimum coal source for their particular boilers, balancing coal quality against cost to efficiently minimize emissions of sulfur dioxide and nitrogen oxides. Already, one PC-based software package from this technology, the Acid Rain Adviser, has been released for use.

ILLUSTRATIONS BY JARED SCHNEIDMAN

In the 20th century, the science of using coal has advanced mightily. The government's Clean Coal Technology Program is breaking new ground on every front: pre-cleaning the coal prior to burning, purifying the combustion process, scrubbing the smokestack gases, and converting the coal to a cleaner-burning gas or liquid (see Combustion Cleanup: The Future is Brilliant). The details of developing new technologies and refining old ones are shared between the DOE's two main labs in Morgantown, W.V., and Pittsburgh, Pa., and hundreds of companies. The Tidd generating plant, for example, is a cooperative effort of the Ohio Power Co., American Electric Power Service Corp., ABB Carbon, Babcock & Wilcox Co., and the Ohio Coal Development Office. The $185 million cost of the project was split between the DOE and the participants. All of the other projects operate along the same lines.

In addition, each DOE laboratory conducts advanced coal research in attempts to further unravel its continuing mysteries. For example, the Morgantown Energy Technology Center's Kinetics/Thermochemistry Lab is looking deep into how coal's worst byproducts are formed at the most basic levels. In Morgantown's Combustion Fundamentals Lab, a droplet of a coal-water fuel mixture is suspended in space by opposite electric charges and turned this way and that as lasers minutely examine how combustion works, its speed, and the best method of doing it.

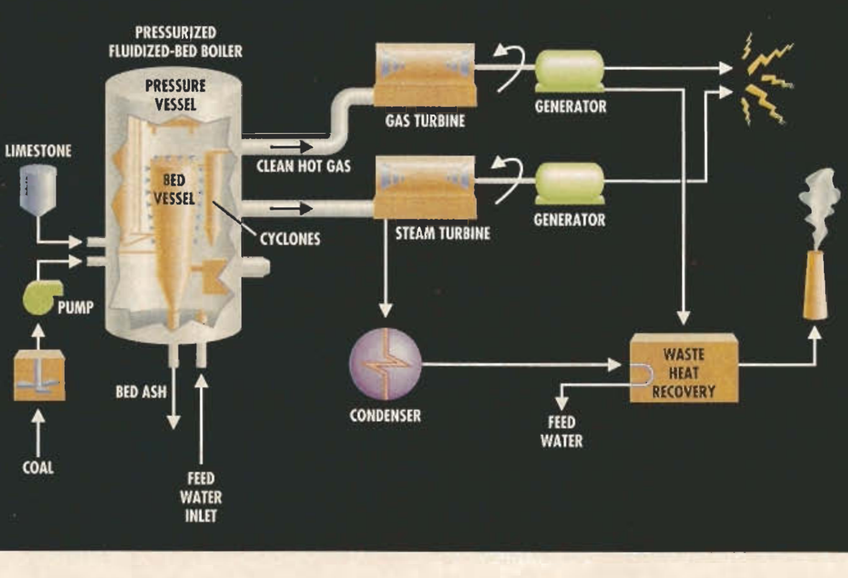
Eighty miles to the north is the Pittsburgh Energy Technology Center, located near a Bureau of Mines working coal mine. Among the specialized units at this facility is the Flue Gas Cleanup Division, one small part of which has been supported by the work of microbiologist Gregory Olson. He has been the driving force behind a project (already under way in Japan) that coaxes microbes to "eat" CO_2, the bête noire of the coal industry. More specifically, says Olson, "there is interest in seeing whether microorganisms can trap CO_2 from flue gas and use sunlight to 'fix' it into biomass. But first we have to see if the microbes can handle SO_2 and NO_x in the hot gas." One possible scenario is a shallow pond with flue gas bubbling up through its bottom into masses of microalgae. Related areas are the bioprocessing of coal for the low-cost production of liquid fuels, and microbial beneficiation, which aims at desulfurization. Olson reports that he'll be testing the *Cyanidium caldarium* organism from Yellowstone National Park, which grows at a low pH number and flourishes in hot water.



Incentives for the 42 DOE technologies stem from the push to clean up the environment, the Clean Air acts, the acid rain imperative, the worldwide tendency to global warming, a desire for energy independence, and the growing cost of energy. One of the not-so-obvious reasons for the DOE's aggressive, multiyear, $4.6 billion program is the burgeoning foreign market for clean-coal technology. China, for example, recently passed the United States as the largest consumer of coal in the world. Most of China's coal-fired plants are completely unregulated; the drive to put refrigerators in 200 million Chinese homes would mean several dozen more large power plants. India, with a 400-year coal reserve, presents an even greater threat to worldwide air quality. Curiously, as U.S. energy *policy* officially shifts away from coal power—even though actual *usage* of coal is on the rise—the need for clean-burning technologies would become more urgent: presumably, that coal will be burned in countries where regulation is far less stringent and air quality standards are much lower than our own EPA demands.

Jack S. Siegel, the DOE's deputy assistant secretary for coal technology, is keenly aware of this vast market poten-

COMBUSTION CLEANUP: THE FUTURE IS BRILLIANT



One of the first large-scale facilities to go online in the DOE Clean Coal project is the Ohio Power Co.'s Tidd Demonstration Plant in Brilliant, Ohio. In this pressurized fluidized-bed combustor, the coal is introduced to the boiler as a finely crushed spray of particles mixed with limestone. Suspended on jets of air, this burning *bed* of coal-limestone mixture appears to be a boiling liquid, lending the *fluidized* terminology, and the combustion vessel is *pressurized* to 165 psi. Emissions are lowered because the limestone absorbs sulfur released during combustion and the tumbling motion of the fuel mixture enables temperatures to be held down to 1600°F, below the point where nitrogen oxides are formed. Efficiency is higher because the boiler gases drive an additional gas turbine, reducing the amount of CO_2 produced for each kilowatt-hour generated.

BORNEO'S SQUEAKY CLEAN COAL

The techniques used to clean up coal before it is burned are aimed primarily at removing naturally occurring sulfur. It's far from cheap: Compliance with smokestack sulfur dioxide levels stipulated by the Clean Air Act are estimated to cost utilities nearly $300 for every ton of sulfur removed.

In Borneo, though, one mining operation is producing coal that, right from the ground, contains one-fifth the sulfur of the cleanest coal found in America. If the sulfur dioxide level from this miracle fossil proves low enough to meet regulations without the use of a smokestack scrubber, the benefits multiply, as total carbon dioxide output would drop by 15 percent. While transporting this pristine fuel from the other side of the globe may not be feasible, its discovery does point out the possibility that much cleaner coal may be available right under our feet. Exploration in modern times has focused on more precious commodities; but with this teaser, there could be a Coal Rush in the offing.

—Norman S. Mayersohn

tial, as well as the need for environmental protection. He has been on coal-oriented economic missions to China and recently headed up the Fossil Fuel Working Party of the International Energy Agency's coal-use meeting in Budapest, Hungary. "Eastern Europe is coal-dominated," he points out, "and does nothing to control pollution. And they're killing themselves. They and the Russians use coal in a big way, but they don't know how to use it. We're making an effort to help."

Much of the coal burned worldwide is high in sulfur and, as a result, a contributor to greenhouse gases and acid rain. When asked what the ideal high-sulfur coal plant would be like, Siegel offers this futuristic scenario: "The ideal plant would be built in modules, shop-fabricated, have no SO_2 emissions, no nitrogen oxide emissions, no toxic emissions, use all waste produced, have efficiencies of 55 to 60 percent, and control and dispose of CO_2."

Are zero emissions attainable? "Probably not," Siegel admits, "but it is possible to get darn close. Some of our programs are getting there; 99-plus percent control of SO_2 and 97 percent control of NO_x, and usable byproducts and efficiency percentages in the 40s is going in the right direction."

"Our plan," says Siegel, "is to see the ultimate really clean coal-burning system in widespread use in the commercial marketplace in the year 2030. Today, fluidized-bed combustors and first-generation Integrated Gasification/Combined Cycle (IGCC) processes are creeping in. The plant of 2030 may involve an integrated gasification fuel-cell technology or some really advanced combined type of gasification system with very high-temperature and high-efficiency gas turbines. It could even be magnetohydrodynamics."

In magnetohydrodynamic (MHD) proposals, electricity is generated directly by passing an extremely hot (5,000°F) stream of gas through a magnetic field. Heated by burning coal in carefully regulated conditions, the exhaust gas retains enough heat (even after the MHD process is complete) to fire a conventional steam turbine, achieving plant efficiencies of 50 percent or greater.

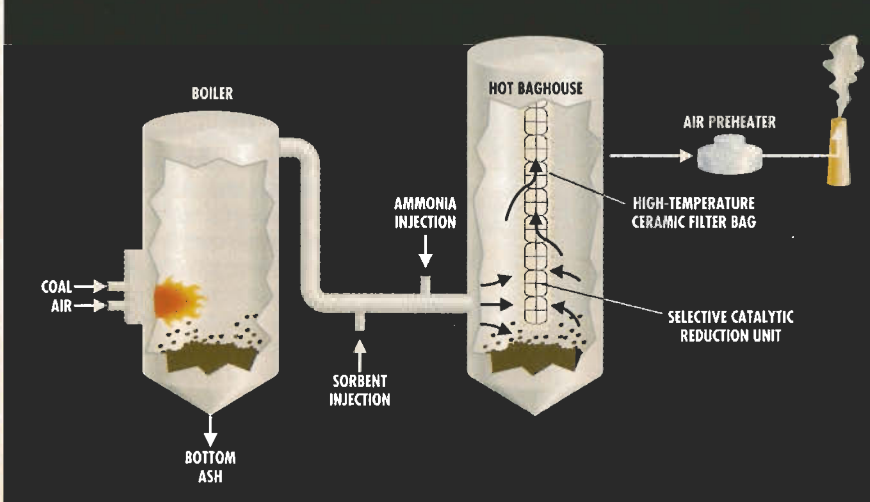
"We've gotten to the point," Siegel noted in 1992, "where liquids from coal would be competitive with oil at $35 a barrel, which is about $18 now. Ten years ago those coal-derived liquids would have competed at $70 a barrel. We know the price can come down another $5 a barrel and that oil will go up."

Siegel says he believes that environmentalists are viewing the DOE's massive undertaking with "cautious interest." Some dedicated environmentalists eye coal with reluctant acceptance, while others are steadfastly opposed. One such doubter is Sierra Club energy lobbyist Daniel Becker. "Clean coal is not clean and never will be. I don't want to give the coal people heart attacks, but we have to phase out the use of coal. The Sierra Club recommends a shift to natural gas and a longer term shift to renewables: solar, wind, geothermal, and fuel cells."

Indeed, utilities are taking a brand-new look at what's good for the consumer and the country, as well as what's good for the utilities themselves. According to the Worldwatch Institute, an environmental research group, the New Mexico Public Service Commission, for example, is investigating the conversion of the huge coal-fired Four Corners Power Plant to natural gas. And it's even listening to an idea to convert to a combined natural gas/solar system. "This," says researcher Nicholas Lenssen of Worldwatch, "is amazing."

Lenssen also has kind words for gasification projects: "This technology gets the best results from coal because you're gasifying coal and then burning it and pushing it

POST-COMBUSTION CLEANUP: SO_x-NO_x-RO_x



A promising technology for retrofit of existing power plants is demonstrated in the flue-gas scrubbing project of Babcock & Wilcox Co., under evaluation at an Ohio Edison facility in Dilles Bottom, Ohio. Removal of sulfur- and nitrogen oxides takes place in a single unit, the high-temperature baghouse. Solid particulate emissions (ROx) are trapped by special ceramic fiber bag filters in this enclosure. Sulfur compounds (SOx) are sponged up by injection of a calcium- or sodium-based sorbent injected into the flue gas. Nitrogen oxides (NOx) are controlled by the selective catalytic reduction process, accomplished by injecting ammonia (NH3) into the flue gas; the resulting reaction produces nitrogen and water. Initial demonstration runs show NOx reductions of more than 90 percent and SO2 reductions of more than 85 percent.

through a gas turbine and a steam turbine. There's no ash from the original burning of the coal.

"But we still have the big stumbling block. Our approach to CO_2 emissions is far behind other countries'. Germany has a national goal of reducing CO_2 emissions 25 percent by the year 2025. Denmark has set a 20 percent reduction by 2005, 50 percent by 2030."

Adds Christopher Flavin, Worldwatch's vice president of research: "It's interesting that the coal technology that gets the lowest emissions and looks the most promising for the future, even though it only reduces CO_2 by 15 percent, is the integrated gasification process. But why do you need to gasify a solid fuel when you already have the gaseous fuel?"

Flavin is off and running, stating that there is clear evidence that pressures for new power generation systems are going to leapfrog over coal entirely with a combination of efficiency programs, natural gas-based co-generation systems, combined cycle systems, and renewables. "Coal and gas," says Flavin, "are in the 100-yard-cleanliness dash, except gas is starting at the 90-yard mark."

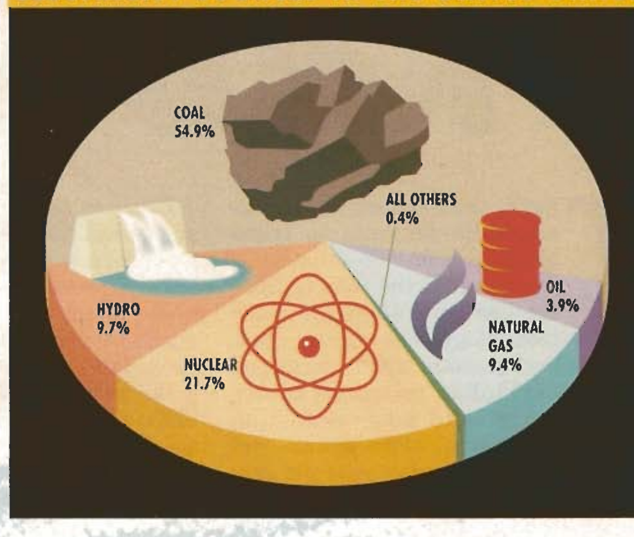
The National Energy Strategy also gets the Flavin ax. "It's an energy future—going out 40 years—based on the increased use of everything we use today, with only minor efficiency improvements and no significant introduction of renewables. Coal use rises dramatically and stays there. Following this scenario, in 40 years the United States would be as energy efficient as Japan is today."

One policy in the wings is that of energy credits or allowances. In this plan, utilities that provide emissions controls receive unit credits for amounts below the legal limit. These credits can then be applied to other plants in the same utility or sold to other utilities.

Consider a hypothetical New York utility, CoalPower. Plant A of CoalPower's two coal-fired generating plants on the Hudson River emits 20,000 tons more of SO_2 than its yearly allowance (which is determined by the state public utility commission). Plant A is fined $1,000 per ton. CoalPower's Plant B, however, limits its SO_2 emissions to 80,000 tons *less* than is required by law. CoalPower now has 60,000 thousand-dollar credits that it can apply to its own Plant A or can sell to another violating utility—and make money. Similar CO_2 credits are also under consideration by the EPA, which handles such matters. And there is a trading exchange on the Chicago Mercantile Exchange that arranges deals between utilities.

Even disregarding the issue of greenhouse gases, the global imperative to make coal come clean will continue to provide a powerful incentive for the research and development community. At the DOE's Oak Ridge National Laboratory in Tennessee, enzymes derived from bacteria are being employed to convert coal into liquid fuels; in Wyoming, 1,000 tons of coal per day are being converted to an oil-like fuel and lightweight, high-energy solid coal by a heated, low- pressure refining process. At the post-combustion end, one new design for smokestack scrubbers that use microwave cookers shows surprising promise as well, with the benefit that it creates no waste sludge in the sulfur removal process. Bringing these advanced technologies on-line will likely be an excruciatingly slow process, fraught with endless environmental impact studies and stalled by the conservative stance of an industry that has taken its share of lumps in Clean Air Act regulation. Still, with reserves underground that could last hundreds of years, and the skyrocketing demand for electric power in developing countries, the quality of life on this planet will unavoidably be tied to just how clean coal can be made. PS

ELECTRICITY SOURCES IN THE UNITED STATES



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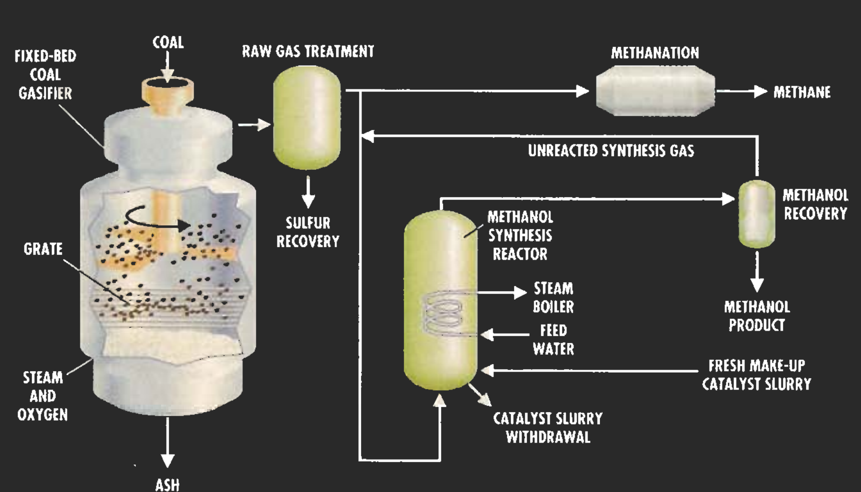
COAL CONVERSION: CHEMICAL FEEDSTOCK, RATHER THAN FUEL



Many scientists present a compelling argument that instead of trying to clean up coal's dirty combustion habits, efforts should be directed at converting the coal to an entirely different form for burning. A number of coal gasification processes—some dating back nearly 200 years—have been forwarded, all representing vast improvements in pollution control; greater efficiency is also possible by siting the refinery near the coal source. The process begins with fixed-bed coal gasification, which employs high-temperature steam and oxygen to break the solid coal into gaseous molecules. The synthesis gas is then processed for methane and fuel-grade methanol production. Sulfur removal on the order of 99 percent is possible, and nitrogen compounds produced in the gasification process are used for manufacturing fertilizer.