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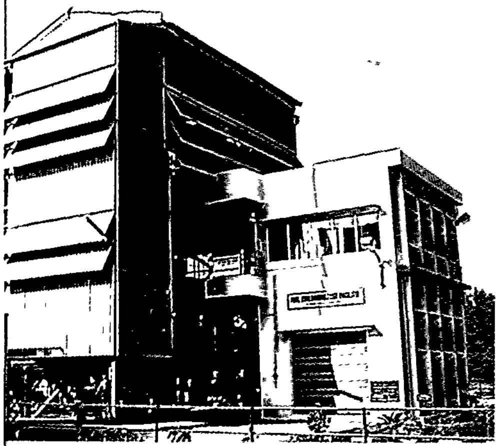

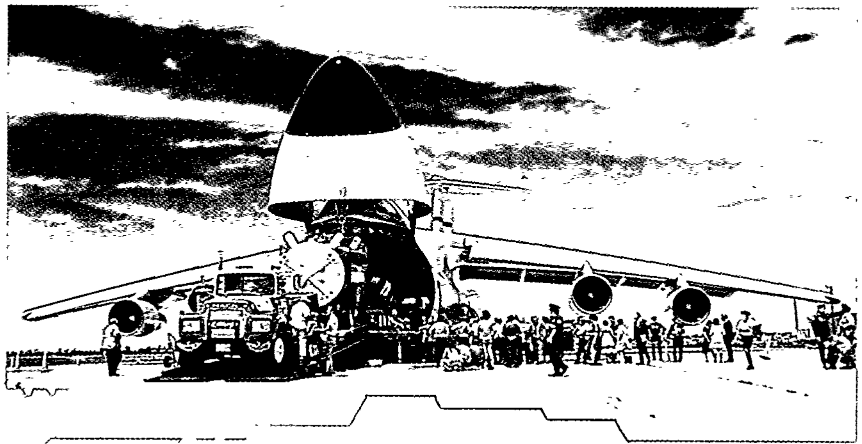

A Global Role for Energy

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PETC
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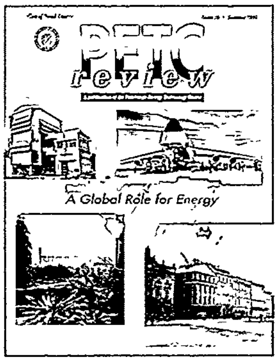
COVER

About the Cover: Cost-effective and environmentally acceptable power generation using coal and coal-based fuels is a primary focus of the Pittsburgh Energy Technology Center (PETC). Because coal will be the principal fuel for electric utilities, both here and abroad for the foreseeable future, PETC is in a unique position to promote clean coal technologies worldwide. This transfer of technology will provide obvious environmental benefits, but it also offers economic benefits by selling American technology and expertise to our global partners. In keeping with this focus, our cover features a map of the world with four images reflecting PETC's involvement overseas. Clockwise from the upper left are: India's Fuels Evaluation Test Facility, a large superconducting magnet being transported to Russia, Thailand's Mae Moh power station, and a view of the central city area of Krakow, Poland.



FROM THE DIRECTOR

Coal is by far the most abundant fuel, not only in the United States, but worldwide. At current consumption rates, the known recoverable coal reserves of the nation are estimated to last for 200 to 300 years. Utility plants consume almost 80% of the nation's annual coal production to produce over half of our electricity. Three countries—the People's Republic of China, the C.I.S. (former U.S.S.R.), and the United States—possess 75% of the world's recoverable coal reserves and currently consume about 55% of the total world production of coal. Much of the rest of the world, though less fortunate in not having such extensive coal reserves, relies heavily on coal for electricity generation. For the foreseeable future, coal will continue to be the principal fuel for electric utilities worldwide. Therefore, it is imperative to continue to find ways to use coal more cleanly and efficiently, both here and abroad.

Sun W. Chun

Much of the research being conducted by PETC has concentrated on developing economically competitive technologies for burning coal more efficiently with fewer emissions. Programs such as the Clean Coal Technology Demonstration Program came into existence to implement those goals. As a result, the United States has a strong lead in developing and implementing clean coal technologies.

In past issues of the *PETC Review*, we have presented several articles that focused on the seriousness of air pollution problems in many parts of the world. Although air pollution is not attributable solely to burning coal without environmental controls, that has certainly contributed to the problem. Because of our commitment and leadership in developing and implementing clean coal technologies, we are in a strong position to help other countries achieve their emission goals. The result will be an improved global environment.

Another goal, especially important in the United States, is creating jobs to sustain economic development. We can contribute to meeting both the environmental and economic goals by international involvement. For example, through meetings and conferences, we can inform other countries of our technologies for controlling pollutant emissions and for increasing the efficiency with which coal is burned. If the other countries see a potential benefit, we can help them to initiate cooperation with U.S. technology developers, equipment suppliers, and engineering companies. The result will be additional jobs in the United States as well as in the country implementing the technology.

To achieve these results, our work with foreign nations takes many forms. We sponsor many international and domestic conferences on fossil-energy-related subjects. PETC engineers work with their foreign counterparts, as we did when working with India on the construction of a Fuels Evaluation Test Facility similar to the one at PETC. We worked with Poland to reduce pollutant emissions from coal-fired plants by managing a solicitation for proposals from U.S. firms to provide technology and by co-funding the subsequent contract work. PETC has Memoranda of Understanding with several countries aimed at sharing information on U.S. fossil energy technology development with them. Researchers and technologists representing a number of different countries have come to PETC, where they gained valuable experience in various aspects of fossil fuel technology.

In these and many other ways, PETC is fulfilling its goals for encouraging international involvement in fossil energy technologies. PETC has been tapped by the DOE Office of Export Assistance to organize overseas conferences to support these goals. The 1992 conference held in Kazakhstan (*PETC Review,* Issue 8) is a good example of the support being performed by PETC in response to its international role in expanding the energy market.

The response we have received from the international participants in all of these programs has been very gratifying. Although we have shared our knowledge with them, we have learned from them as well. Our personnel have learned about working in foreign countries and with foreign economies. They have also benefitted by gaining an understanding of how U.S. technologies can be adapted to international needs.

There is so much benefit to be gained from this work by all participants and so much left to be learned that the next decade promises to be very exciting for us all. We realize that even if we fully implement clean coal technologies in the United States, the worldwide growth in emissions of carbon dioxide and other pollutants will continue to increase. By promoting investment in low-cost, innovative clean coal technologies worldwide, we can help to solve our global environmental problems together.

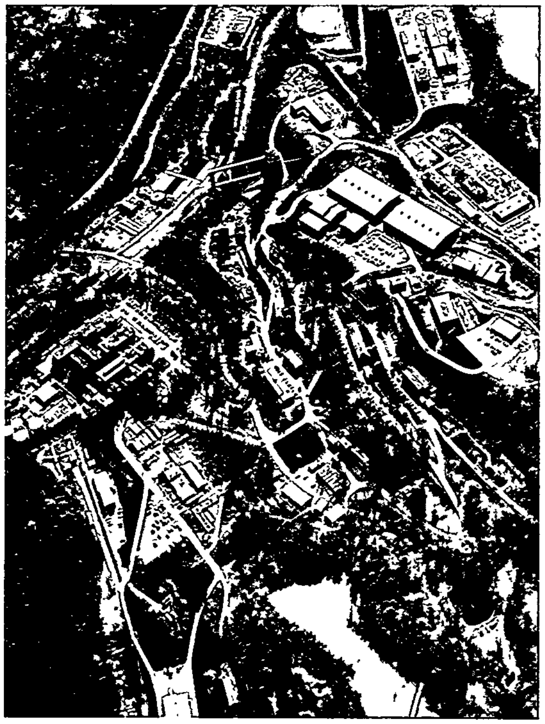
Sun W. Chun

Sun W. Chun
Director

BUILD IT AND THEY WILL COME

Because of its past accomplishments and the activities of its employees, the Pittsburgh Energy Technology Center (PETC) has a high international profile and ongoing cooperative agreements with several countries. For example, in the 1993 fiscal year alone, PETC was host to more than 140 international visitors, including government officials, industrial executives, and academicians. In 1910, the Federal Government built its first coal research center in Pittsburgh, Pennsylvania, and international (as well as domestic) visitors have been coming to it ever since.

Visitors come to PETC for a variety of reasons: to participate in the many U.S. Department of Energy (DOE) international assistance and technology transfer programs; to collaborate in research and publications; to train in PETC's in-house research facilities; to confer with their counterparts in research, development, and program functions; and to attend meetings and conferences.



This aerial view of the Bruceton Research Center shows the present day site of DOE's Pittsburgh Energy Technology Center. The site, about 10 miles south of Pittsburgh, is also home to the Pittsburgh Research Center of the U.S. Bureau of Mines, and a Mine Safety and Health Administration facility.

PETC's history of international collaboration goes back at least to 1926, when, as the Central Research Station of the U.S. Bureau of Mines, it hosted the First International Conference on Bituminous Coal in Pittsburgh, Pennsylvania. In subsequent decades, the Center was the country's principal facility dedicated to research on coal. As such, PETC attracted visitors from the rest of the world who were interested in the study of coal. The energy crisis of the 1970s heightened interest in coal research by an order of magnitude. During that same decade (in 1977), PETC became a DOE laboratory, and this fact combined with the interest generated by the energy crisis resulted in an increase in the number of international collaborations and visits.

Since the 1926 First International Conference on Bituminous Coal, PETC has hosted or sponsored dozens of international meetings in Pittsburgh and at other sites throughout the country. Each such meeting also draws foreign researchers to PETC, where they are able to confer with their PETC counterparts, exchange information, and frequently, present seminars.

In addition to numerous other conferences that attract foreign attendees, PETC has been a co-sponsor, since its inception, of the Annual International Pittsburgh Coal Conference, which is held in Pittsburgh each September, and of the

Annual International Technical Conference on Coal Utilization and Fuel Systems, which is held (in recent years) in Clearwater, Florida, in March or April. PETC was also the host for the 1983 International Conference on Coal Science held in Pittsburgh (see p. 17 this issue).

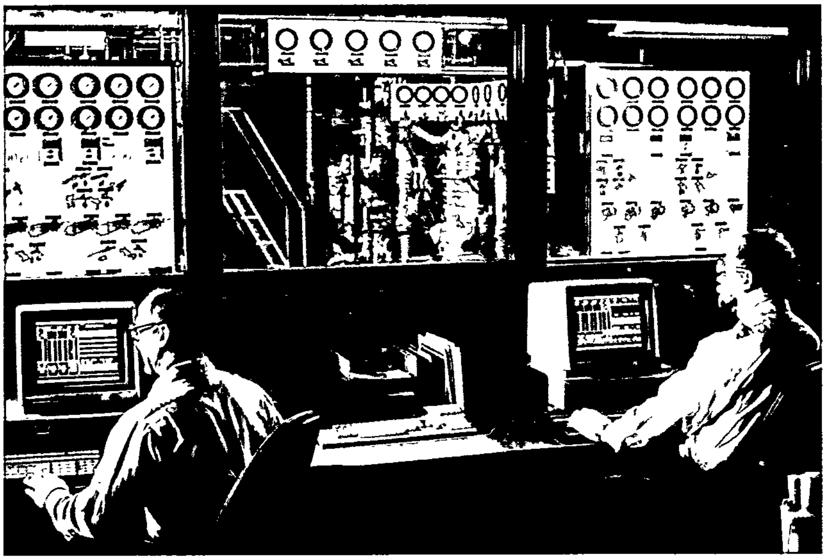
For several years, PETC has been the U.S. host for the Annual U.S./Japan Joint Technical Meetings in various coal technology areas. These meetings alternate between Japan and the United States; the 1994 meeting was in Hokkaido, Japan. PETC is also the U.S. host for the U.S./Korea Joint Workshops on Coal Utilization, which are held alternately in Korea and the United States.

The first United States/United Kingdom NO_x Workshop (*PETC Review,* Issue 7, p. 41) was held at PETC June 13 to 15, 1992. Both nations are making serious efforts to substantially reduce nitrogen oxides (NO_x) emissions. Important future research needs were highlighted at the workshop. Further U.S./U.K. collaboration will attack these problems and will explore novel, futuristic concepts for NO_x control.

In September 1993, PETC hosted a full-day meeting with U.K. researchers to discuss mutual interests in coal liquefaction. The exchange of information was beneficial to both parties. For example, as a result of recent success reported by the British workers using filters to separate the resid fraction from liquefaction, PETC is reexamining filtration as an alternative to the Kerr-McGee supercritical solvent extraction process currently being used.

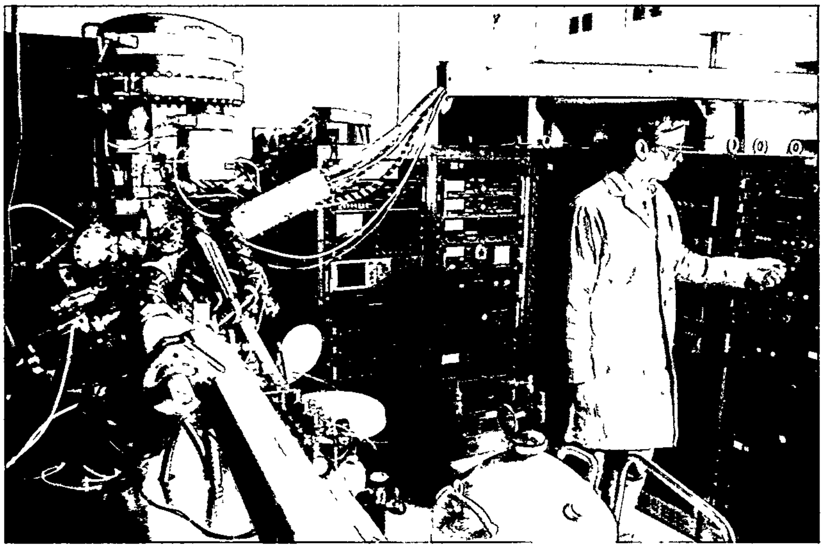
Uncommon Capabilities

Because PETC is a federal laboratory, its in-house research and development is not proprietary except for protected information generated under Cooperative Research and Development Agreements (CRADAs); therefore, its personnel are not inhibited in discussions with visitors, as they might be in an industrial environment. In addition, as a federal facility, PETC is perceived as being able to provide an insider's view of the government's policies and role in fossil energy. These considerations make PETC an inviting place for foreign visitors.



PETC's hydrotreater unit is designed to convert coal to liquid fuels under high pressure and to upgrade heavy oils.

Perhaps PETC's greatest attraction is its long and illustrious role as a coal research laboratory with uncommon capabilities. Although other well-equipped analytical facilities exist, PETC is unique in its history and broad experience of applying state-of-the-art techniques to coal, coke, and coal-derived materials. Many of the analytical methods currently used for coal were formulated and developed in the Center's analytical laboratories and were incorporated into the accepted standard procedures used by coal laboratories worldwide. The current standard procedures for proximate analysis of coal (moisture, volatile matter, and fixed carbon) and ultimate analysis of coal (principal elemental analyses) were first published by PETC's researchers when it was still in the Bureau of Mines. These procedures formed the basis of the methods adopted by the American Society for Testing and Material—the ASTM Standard Methods. Many of the other ASTM Standard Methods were based on procedures developed in the PETC laboratories. The standard reference samples used for measuring Hardgrove Grindability Index, a measure of the grindability of coal, are prepared at PETC and provided (for a fee) to laboratories worldwide. PETC has been the federal referee laboratory for coal analysis; as such, its data have been accepted by the courts in federal lawsuits involving coal.



PETC's X-ray photoelectron spectrometer is used to perform surface or near-surface elemental analyses.

PETC has pioneered the adaptation of new methods to coal research and has originated procedures that were initially intended for coal but have achieved much wider applications. Gas chromatographic (GC) analysis of coal-derived liquids was initiated at PETC using a GC instrument designed and built on site even before commercial instrumentation was available. This analytical procedure led to the first use of trimethylsilyl derivatization and to the development of the ternary reagent consisting of hexamethyldisilazane, trimethylchlorosilane, and pyridine for forming derivatives of hydroxyl and phenolic (-OH) groups. The reagent, developed and first used for the measurement of phenolic groups in coal, subsequently became a standard derivatization reagent that is still widely used in sample preparation for gas chromatography.

Always among the first organizations to apply new techniques to coal research, PETC provided some of the early spectroscopic investigations in several areas. To the Center's credit, PETC was the possessor of several instruments with single-digit serial numbers, which indicates early entry into the use of the technique. However, being a pioneer in research also meant suffering through the problems associated with early versions of equipment. The reward was the opportunity to contribute to opening up new techniques, using coal as the substrate on which to base experimentation. Some of the earliest work on measuring ^{13}C nuclear magnetic resonance spectra was carried out on coal at PETC. One of the first applications of low-voltage, high-resolution mass spectrometry to the group analysis of complex mixtures was performed on coal liquids by PETC analysts.

PETC has been applying spectroscopic procedures to coal and its derivatives since the formative stages of these techniques. Applied procedures include infrared; nuclear magnetic resonance, both proton and ^{13}C; electron spin resonance; and low-voltage, high-resolution mass spectrometry. In each of these techniques, PETC has made contributions not only in their application to coal but also to the general understanding and application of the techniques to classes of compounds and to the structure elucidation of pure compounds and reaction intermediates. In addition, PETC uses other current spectroscopic tools in its continuing research efforts, including scanning electron microscopy, X-ray diffraction, and X-ray photoelectron spectroscopy.

Between the 1930s and the 1960s, PETC was one of the few, if not the only, research organizations in the United States that was involved in coal liquefaction, both direct (by hydrogenation) and indirect (by Fischer-Tropsch chemistry). Therefore, PETC established a worldwide reputation for its studies into the mechanism of the chemistry involved in the reactions and behavior of coal.

As an adjunct to its research on Fischer-Tropsch chemistry, PETC was one of the first, and for a time one of the very few, laboratories in the world studying the chemistry of and catalysis by metal carbonyls. This led to a practical synthesis of octacarbonyl dicobalt, an important catalyst in the Oxo reaction, in which carbon monoxide and hydrogen are added to the double bond in an olefin to produce an alcohol (see sidebar). PETC became the world's only source of this catalyst for research purposes until several commercial laboratories (operated by former PETC employees) made it available.

For decades, PETC's facilities and personnel have been acknowledged as international leaders in coal preparation technology. Today, PETC's Coal Preparation Division operates a modern facility, which can demonstrate the application of any preparation technology on coal at throughput levels up to 500 lb (225 kg) per hour (see *PETC Review*, Issue 5, "PETC's Coal Preparation Process Research Facility"). This showcase facility is the focal point for many coal technologists from Japan, Korea, China, India, Australia, Poland, Russia, Turkey, the United Kingdom, and Canada. These visitors are interested in the latest coal-cleaning technologies being tested in the facility. These are technologies that the United States can export to interested countries.

In the past two decades, PETC has expanded its interests in response to the variety of demands and restrictions that have been placed on the use of coal. The result has been in-house research on such areas as coal desulfurization; microbiology involving fossil fuels; flue gas clean-up involving both sulfur dioxide (SO_2) and NO_x removal; improved combustion methods; coal-slurry transport, stability, and combustion; solids transport; and magnetohydrodynamics.

PETC's long and distinguished experience as a federal coal research facility makes it of interest to the international coal research community. The Center's ongoing work continues to attract international visitors and attention.

Visitors from Abroad

Poland

As a result of several visits by PETC researchers to evaluate the Polish efforts in coal preparation and liquefaction, a small but steady stream of Polish coal researchers has come to the labs at PETC. They came to study the various aspects of flue gas desulfurization, liquefaction, and analysis. This group has included academics, scientists and engineers from coal research institutes, and personnel from industrial plants. In the last several years, their interest has shifted toward decreasing air pollution. Many Polish governmental and industrial representatives have visited PETC to discuss projects in Poland to decrease air pollution (*PETC Review*, Issues 2, 3, 5, and 8) as well as to get hands-on experience in the related laboratory techniques.

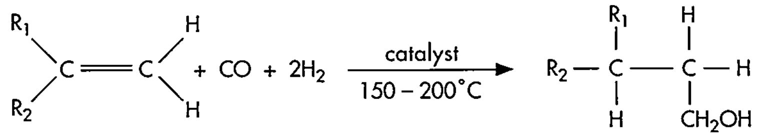
PETC's Coal Utilization Division has hosted several delegations of Polish visitors. Along with discussing details of and participating in meetings concerning technical solicitations for cooperative U.S./Polish projects, these visitors were very interested in PETC's in-house R&D laboratories.

Korea

The relationship between PETC and Korea has been especially active. In 1982, a memorandum of understanding was signed between the United States and Korea, allowing PETC to interact on behalf of DOE in a cooperative laboratory relationship with the Korea Institute of Science and Technology (KIST) and the Korea Institute of Energy Research (KIER) in the area of coal use and technology. Following a visit to Korea by PETC Director, Dr. Sun W. Chun, PETC received many requests for information and assistance. Arrangements were made for representatives of the two institutes to travel to PETC for short- and long-term assignments for training and technology transfer. Through this program, about 100 Koreans have visited PETC

THE OXO REACTION

The Oxo reaction, or the hydroformylation reaction, involves the addition of carbon monoxide (CO) and hydrogen (H_2) to the double bond of an olefin, catalyzed by a transition metal compound.



The Oxo reaction is related to the Fischer-Tropsch reaction (see *PETC Review*, Issues 2 and 4) in that both involve reactions of CO and H_2 and transition metal catalysts, and indeed, the Oxo reaction was discovered by Otto Roelen in Germany in 1938 while doing research on the chemistry of the Fischer-Tropsch reaction. An important difference is that the Fischer-Tropsch reaction uses a solid, insoluble catalyst and the Oxo reaction uses a soluble catalyst, the most common of which is octacarbonyl dicobalt, $Co_2(CO)_8$. During studies on the two reactions, researchers at PETC developed a convenient synthesis of this important catalyst. Before this, preparation of research quantities of the catalyst had been inconvenient and produced only small quantities at a time. Industrial-scale work relied on *in situ* preparation of the catalyst species, which was never recovered as such.

The Oxo reaction is used to produce large quantities of higher alcohols from petroleum-based olefins. These alcohols are used in the production of plasticizers (e.g., dioctylphthalate) for plastics, in conversion to surfactants, and as solvents.

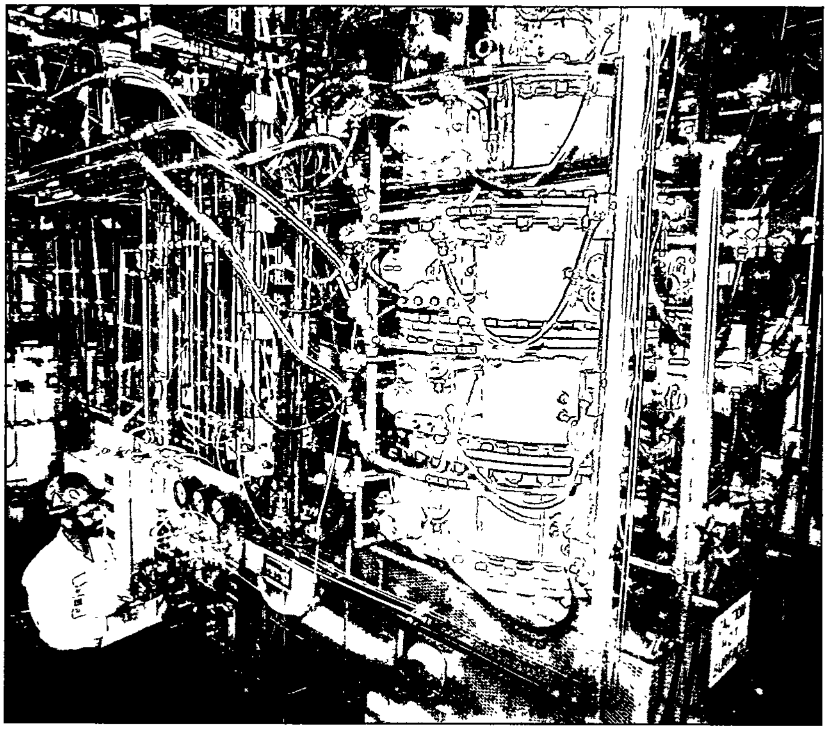
since 1982. PETC has also provided technical consultation to KIER and to KIST by sending PETC scientists and other U.S. corporate representatives to Korea—over 15 have visited Korea since 1982.

The Korean visitors' areas of interest have included coal preparation, combustion, pollution control, alternative fuels, and coal liquefaction. One recent representative of KIER participated with the Direct Liquefaction Division for a year in their program to develop and examine impregnated coal liquefaction catalysts.

People's Republic of China

PETC's pre-eminence in coal research has created a strong attraction for scientists and engineers from coal research institutes in the People's Republic of China, the world's leading producer and user of coal. An engineer from the Institute of Coal Chemistry, Academia Sinica, spent 2 years at PETC in the early 1980s to work on modeling the high-pressure fluidization of coal. This collaboration with PETC researchers resulted in more than a dozen publications. Many other Chinese researchers have been on assignments to PETC for extended stays to study direct and indirect liquefaction, liquid fuel combustion problems, analytical instrumentation for characterization of coal and coal liquefaction products, and slurry Fischer-Tropsch catalysts.

PETC's Combustion and Environmental Research Facility is used to examine a variety of fuels and to test novel control systems and combustion technologies.



The Chinese have recently sent representatives to confer with PETC and U.S. Bureau of Mines personnel who are conducting experiments jointly on "heap-leaching" of pyrite (FeS_2) from coal. This procedure uses the natural microbiologically assisted, ambient moist oxidation of pyritic sulfur to form a soluble sulfate ion ($SO_4^=$), which is then leached from the coal pile by recirculated water.

Italy

The "heap-leaching" project brought another visitor to PETC from Italy who spent 6 months doing research on the biodepyritization of coal by the organism *Thiobacillus ferrooxidans* in collaboration with the PETC microbiology group. This work, which was part of the Center's ongoing effort on this topic, resulted in several joint publications.

Italy, although a fuel-poor nation, maintains a high visibility in energy research. This has been most notable in catalysis research relating to the chemistry of synthesis gas, a mixture of hydrogen (H_2) and carbon monoxide (CO) formed by partial oxidation of a fossil fuel. From this gas mixture, it is possible to produce motor fuels, a large variety of chemicals, and methane. PETC's long involvement in research on this chemistry has attracted a number of researchers from Italy who worked for extended periods with PETC chemists and engineers. They have come principally from two industrial companies—Snamprogetti and Eniricerche—which are engaged in research on heterogeneous catalysis and alcohol synthesis related to the Fischer-Tropsch reaction (*PETC Review*, Issues 2 and 4).

Spain

During the summer of 1993, PETC hosted a doctoral candidate from the Institute of Carbochemistry, University of Zaragosa, Spain, who tested catalysts for coal liquefaction, including those she was using in her Ph.D. work in Spain. The catalysts were characterized by scanning electron microscopy, Mossbauer spectroscopy, and by tests in PETC's hydrotreater facility.

The Former Soviet Union

PETC's interests in magnetohydrodynamics (MHD) has attracted representatives from a number of countries. The former U.S.S.R. had an extensive MHD program that included a joint project with the United States that brought numerous visitors to exchange information with PETC personnel. As part of the project, DOE provided a large superconducting magnet to the U.S.S.R.

Programs and Facilities that Attract International Attention

Facilities

An area of specific interest to Korea has been PETC's 0.15-MW Combustion and Environmental Research Facility (CERF), formerly the Fuels Evaluation Facility. The CERF provides a thoroughly instrumented combustor for examining combustion properties of a variety of fuels, including coal slurries, and for testing novel control systems and combustion technologies. This multipurpose facility has attracted visitors from many countries, especially from Korea and India. In both countries, the CERF is serving as a prototype for the construction of similar combustion test facilities that are being built.

India and PETC are even more deeply involved in fuels evaluation activities. As mentioned elsewhere (*PETC Review*, Issue 9, "International Corner: India"), a Fuels Evaluation Test Facility (FETF), similar to the CERF at PETC, is being built in India with sponsorship by the United States Agency for International Development and with considerable technical support from PETC. Several engineers from Bharat Heavy Electricals Limited, the Indian company constructing the facility, have spent considerable time at PETC examining combustion behavior of Indian coals using the PETC CERF. These results will be used to provide baseline data for the Indian FETF. PETC has provided construction information and training to visiting Indian engineers, and has also sent PETC personnel to India to assist in planning support for the FETF.

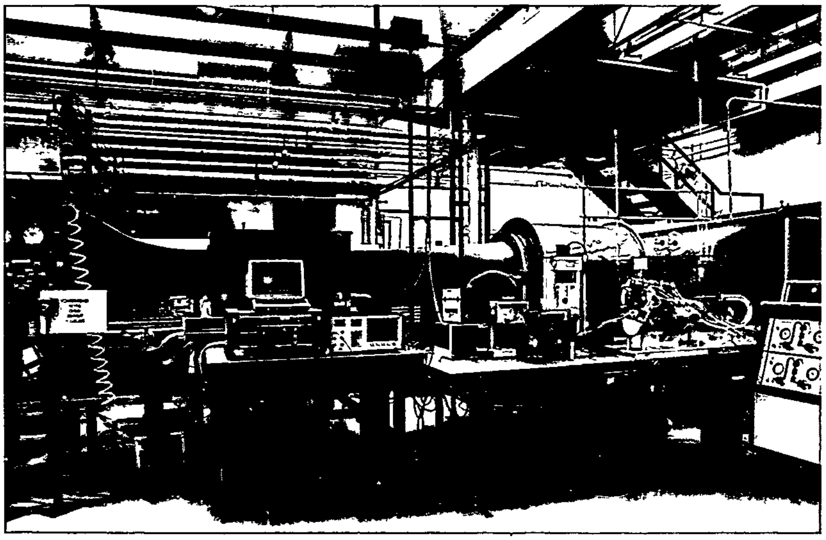
FOSSIL ENERGY INTERNATIONAL STRATEGIC PLAN

Each billion dollars of U.S. goods and services sold overseas is estimated to create about 20,000 domestic jobs at a median wage that is 17% higher than the current average U.S. wage. If we can improve our competitive position in the world market, U.S. export volume and jobs for domestic workers will increase. In recognition of these facts, the United States has developed a National Export Strategy, which will be implemented by the Trade Promotion Coordinating Committee (TPCC). In keeping with the spirit of the TPCC effort, the Acting Assistant Secretary for Fossil Energy (within the U.S. Department of Energy) commissioned an International Task Force to develop a Fossil Energy International Strategic Plan. The task force was instructed to keep in mind the visions of the Administration of global environmental protection; domestic economic development, including the creation of United States jobs and the export of United States goods and services; and the roles and responsibilities of the elements of the Department of Energy (DOE) and the Federal Government.

Once the strategic plan was approved, the task force began developing regional implementation plans that include descriptions of

- organizational roles and responsibilities;
- resource needs, including financial and personnel;
- milestones and workload sequencing to accomplish the strategy;
- detailed guidelines for developing a communication and marketing plan;
- quantifiable performance indicators; and
- information obtained from stakeholders about the strategic plan.

The mission of the Fossil Energy International Program is to support DOE objectives to improve the U.S. economy and enhance U.S. competitiveness and technological advantage, more effectively manage U.S. energy resources, and increase U.S. and global energy security. As part of this mission, the regional implementation plans are being developed to provide a framework of focused and interrelated activities and procedures that will result in the achievement of DOE goals.



PETC's Particulate Flow Analysis Facility designed to study the flow dynamics in coal utilization processes has also been used to study the hemodynamics of artificial heart pumps and the flow fields in artificial lung devices.

Programs

The Solids Transport Program attracts considerable international interest. The areas of coal-water and coal-oil slurries are of intermittent commercial interest whenever petroleum prices rise sharply. When PETC initiated its slurry studies in the early 1970s, the major interest was domestic; in recent years this has changed. Today, it is Europe and Asia, especially China, that have become the leaders in slurry application. There is interest, as well, in South America and Africa. As a result of this worldwide attention, visitors from many countries come to PETC to take advantage of PETC experience. SASOL, the huge government-sponsored coal conversion company in the Republic of South Africa, has sent several engineers to PETC to discuss the behavior of coal-water slurries. Snamprogetti, of Italy, has had personnel visit PETC to obtain coal-water slurry information applicable to its work in constructing fuel transport pipelines from the former Soviet Union into Western Europe. By far the largest groups of visitors who have come to PETC to discuss coal slurries have been from China.

One of PETC's unique facilities is its Particulate Flow Analysis Facility (PFAF), which uses sophisticated flow diagnostic equipment to study flow fields, especially in heat-exchanger tube banks of coal-fired boilers (*PETC Review*, Issue 4, "PETC's Flow Analysis Laboratory Assists Artificial Heart Research"). In a very unusual marriage of unrelated research efforts, the PFAF has been used to study blood flow behavior in artificial heart devices. These two very different uses of the PFAF have interested a variety of international visitors; some have been interested in boiler tubes and others have been interested in the serendipitous work in bioengineering.

The Benefits of International Involvement

Clearly, the international community has greatly benefitted from PETC's extensive and varied research capabilities and from the ability to assemble researchers with knowledge and expertise in many technology areas related to coal. PETC is unique in having both the breadth and depth in coal-related technologies that can be directed to solving problems. As a result of these qualifications, PETC has been the center to which the overseas coal research and technology community has been attracted.

On the other hand, PETC and the United States also benefit from these visitors. They leave behind knowledge that they have brought with them, for there is something to be learned from every scientific interaction. More important to our nation, however, is what the international visitors take with them from PETC. When they return to their native countries, they take with them familiarity with U.S. technology and an incentive to import that technology into their own expanding energy programs. From that perspective, PETC serves as a showcase for the nation's know-how and the Fossil Energy International Strategic Plan (see sidebar).

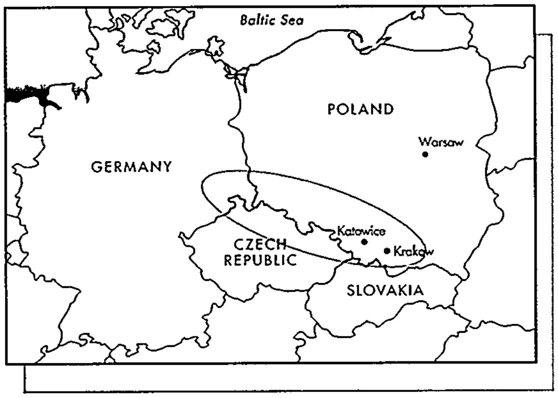
PETC'S OVERSEAS ACTIVITIES

Although the U.S. Department of Energy/Office of Fossil Energy (DOE/FE) is developing an International Strategic Plan for future application, PETC has been active in international coal technology for several decades. Since the early 1970s, PETC staff members have been traveling abroad, initially to exchange information but more recently as unofficial ambassadors of U.S. fossil energy technology.

The coal research and technology community has a long tradition of international activity. In the early part of this century, most of the flow of information was from Europe, particularly England and Germany, to the United States. After World War II, the direction changed, and ultimately the United States became the principal coal technology nation. PETC has played and continues to play an important role in representing the United States abroad.

Cleaning the Air in Poland

Perhaps PETC's most extensive overseas involvement has been with Poland, one of the world's largest producers and exporters of coal. For many years, Poland has supported several research institutes that are devoted to coal and has been actively engaged in developing coal-based technology. PETC's overseas activities in Poland began in the early 1970s, at a time when world interest in coal liquefaction was reviving because of global oil supply and pricing disruptions. Poland—coal rich and oil poor—was interested in converting some of its coal to oil. At that time, most Eastern European nations were on less-than-friendly terms with the United States; however, Poland welcomed delegations of PETC personnel for extended visits to provide assistance in their coal preparation and liquefaction programs. Although interest in coal liquefaction subsequently waned in both Poland and the United States, the relationship established between PETC and the Polish coal industry remained strong, and it was to DOE/PETC that Poland turned for assistance in the latter part of the 1980s. The request for assistance came after a visit by then-President George Bush to Poland and after his publicly stated commitment to aid Poland in its pollution-control efforts.



Shaded area shows Silesia and neighboring areas affected by severe air pollution problems, due in part to the inefficient burning of coal.

The worldwide problem of air pollution was particularly severe in Silesia, which is located in Southern Poland. Here, as well as in neighboring Germany and The Czech Republic, the uncontrolled and inefficient burning of coal was causing increasing air, soil, and water pollution; eroding the stone of buildings and monuments; and threatening the health of the residents. In this smog-covered area lies Krakow, the former Middle-Ages capital and third-largest city in Poland. Both the Polish government and the municipal government of Krakow were anxious to remedy the environmental situation. In 1989, talks were initiated between DOE and the Polish Ministry of Environmental Protection, Natural Resources, and Forestry.

Air pollution and acid rain have eroded nearly all detail from this statue in Krakow. *Photo courtesy of Richard A. Liroff, World Wildlife Fund.*

Within months, a U.S./Polish Bilateral Steering Committee, which included a PETC representative, was established to oversee a two-part plan aimed at reducing emissions from coal-fired electric utility plants, coal-burning heating plants, and household stoves in Krakow.

Since the inception of the Steering Committee, PETC has been heavily involved in the negotiations between the two countries and in the implementation of the resulting agreements. (Details of these agreements have been described in *PETC Review*, Issue 2, "United States Clean Coal Technology Exported to Poland," and Issue 8, "International Corner: Poland, Kazakhstan, and Russia.") The initial U.S. funding for the joint U.S./Polish initiative came from money appropriated by Congress in 1989 for the Support for Eastern European Democracy (SEED) Act to support projects related to reducing emissions and improving energy efficiency in Eastern European countries.

The Skawina Power Plant

The first goal of the cooperative U.S./Polish agreements is to reduce the pollution from utility plants that burn the indigenous, high-ash, high-sulfur, low-energy-content coal. In 1990, DOE/PETC initiated the process to select a U.S. company to manufacture, in the United States, a sulfur dioxide (SO_2) scrubbing system for retrofit on a 50-MWe coal-fired boiler at the Skawina Power Plant near Krakow. PETC was responsible for preparing, issuing, and administering the Request for Proposal that led to the award to AirPol Inc., of Teterboro, New Jersey, to fabricate and direct the installation of the scrubber. The magnesium-enhanced-lime scrubber can reduce SO_2 emissions by 98%.

This power plant is one of 1,300 of the relatively small and inefficient coal-fired district boilers found throughout Krakow.

Even before the dedication of this scrubber unit, the Skawina Power Station had provided additional funding to retrofit scrubber facilities on another boiler. This represents the first "export" of a U.S. technology that was part of this international agreement.

The Skawina Power Plant scrubbing system is expected to be a showcase for all of Eastern Europe. The other countries, and especially those in the neighboring Silesian pollution zone, will be able to obtain information about the equipment and the results at Skawina and to gain further guidance from PETC personnel on adapting the appropriate technology to specific situations. Skawina will also serve as a training site for prospective European buyers of the technology.

The Krakow Clean Fossil Fuels and Energy Efficiency Program

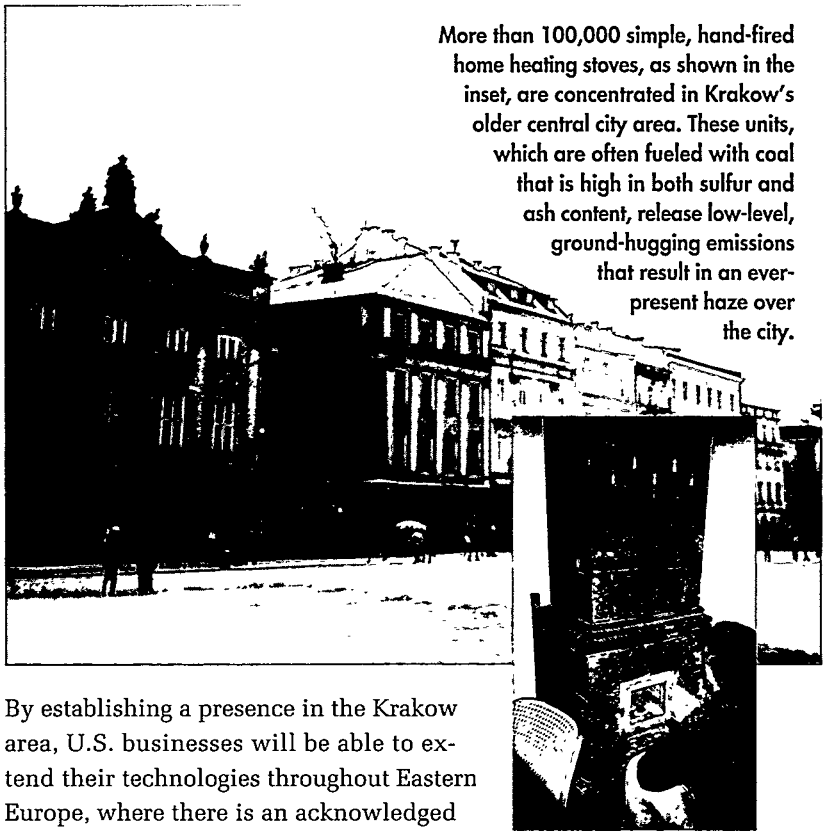
The second goal of the U.S./Polish cooperative agreements is to reduce the air pollution in Krakow. Like many large European and U.S. cities, Krakow relies on centralized heating and hot-water boilers. In Krakow, these 1,300 coal-fired district boilers are relatively small and inefficient. In addition, more than 100,000 simple, hand-fired home heating devices are concentrated in the crowded central city area. All of these units release low-level, ground-hugging emissions that envelop the city in an ever-present smog. A U.S./Polish Memorandum of Understanding initiated a program to reduce this pollution at a cost that the Polish citizenry is willing to accept.

U.S. funding for this program is being provided through the United States Agency for International Development (USAID). The United States has committed $20 million to the program. PETC has been chosen to implement and manage all DOE fossil-energy-related work for this program. Overall direction is provided by an eight-member Bilateral Steering Committee that includes representatives of USAID; DOE; PETC; Krakow; and the Polish Ministry of Environmental Protection, Natural Resources, and Forestry.

An initial inventory was made of the boilers and heaters, and data were gathered on their emission characteristics and mode of use. PETC initiated an assessment of these data with assistance from municipal authorities in Krakow and DOE's Brookhaven National Laboratory (BNL). This assessment showed that burning cleaned coal or burning coal in an environmentally sound manner would be nearly as effective at a much lower cost than other heating alternatives. Pilot tests on the district boilers and home stoves were conducted with the help of personnel from BNL and the Biuro Rozwoju Krakowa (BRK, the Krakow Development Office). With this information, PETC staff and the BRK analyzed the factors that contribute to Krakow's air pollution and evaluated potential solutions to the problem.

Following public meetings in the United States and in Krakow to publicize the program, DOE/PETC issued a Program Opportunity Notice solicitation for proposals from U.S. firms for cost-shared cooperative agreements. Program funding of $14.5 million was allocated for the U.S. Government's share of the cooperative agreements. U.S. firms were required to cost share at least 50% of each proposed project. These agreements would support the establishment of commercial ventures for cost-effective approaches to reduce emissions in the Krakow area. Evaluation of the proposals by a DOE Source Evaluation Board resulted in the selection of nine proposals for funding.

These cooperative agreements should be completed by 1998. Projections of the effectiveness of the proposed technologies predict sizable reductions in emissions of hazardous hydrocarbons and SO_2, as well as a 90% reduction in particulate emissions at an increase in heating costs of about 11%. A survey of public attitudes has indicated that Krakow residents are willing to pay the increased heating costs associated with the pollution-reduction approaches selected for the program.



More than 100,000 simple, hand-fired home heating stoves, as shown in the inset, are concentrated in Krakow's older central city area. These units, which are often fueled with coal that is high in both sulfur and ash content, release low-level, ground-hugging emissions that result in an ever-present haze over the city.

By establishing a presence in the Krakow area, U.S. businesses will be able to extend their technologies throughout Eastern Europe, where there is an acknowledged need for pollution remediation. Also, the "lessons learned" and experience gained in dealing with foreign countries will help DOE/FE implement its International Strategic Plan (see this issue, "Build It and They Will Come").

The various phases of the U.S./Polish cooperation have necessitated considerable involvement of PETC personnel, including numerous trips to Poland for on-site evaluation, consultation, and project management functions. This experience, as well as the many other international activities carried out by PETC, will enable PETC to play a larger role in future DOE involvement in overseas energy opportunities.

The Former Soviet Union and the Newly Independent States

As was true for most areas of contact, relations between the United States and the former Soviet Union in fossil energy research and technology vacillated between cold and tepid. There was at least one fossil energy research area in which cooperation actually reached the stage of collaboration—magnetohydrodynamics (MHD). PETC, which became involved in MHD research transportation/transmission, conversion, and use of fossil-energy-driven power generation. Previous development of these resources and systems during the past 75 years had been directed under policies set forth by a central-planning regime without recourse to market forces. Before the current period, little or no modernized industrial activity existed in any of the countries that made up the former Soviet Union.

Russia and the other Newly Independent States are an attractive market for U.S. technology. These areas are a potential market for fossil energy technologies and need to adopt new and cleaner environmental technologies to sustain current production levels. However, transacting business in this region can be difficult because of the changes in government and unclear laws of private ownership. The potential is there for U.S. industry—but an operational framework with the cooperation of DOE/FE and other federal agencies must be put in place.

A large superconducting magnet is loaded onto a C-5 transport plane for shipment to Russia. The U.S. government "loaned" the magnet to the Soviets as a result of a working relationship that developed between PETC researchers and their Soviet counterparts involved in MHD research. A recent agreement allows for the magnet to be transferred to China for additional research work.

over 25 years ago, was part of a small but dedicated group of international researchers. The Soviet MHD group was, uncharacteristically, a sometime active participant, resulting in an open exchange of information between PETC and the Soviets. The culmination of this relationship was the "loan" of a large superconducting magnet to the Soviet MHD effort by the U.S. Government, with the understanding that the Soviets would share the results with us. In a recent three-way arrangement, the magnet is to be transferred to China, where there is currently an increased interest in MHD (see *PETC Review,* Issue 6, "Magnetohydrodynamics").

With the dissolution of the Soviet Union, PETC has acquired a new role in dealing with Russia and the new Eurasian Democracies. In 1992, Congress passed the Freedom for Russia and Emerging Eurasian Democracies and Open Markets (FREEDOM) Support Act, which is designed to encourage developing democracies and open-market economics. The act promotes policies and technology transfer that will reduce energy waste, encourage environmental awareness, and improve efficiency of production and transportation of fossil fuels. As DOE's representative, PETC has been assisting USAID and several components of DOE (Office of Energy Efficiency and Renewable Energy, Office of International Affairs, and Office of Export Assistance) in promoting U.S. energy technologies, equipment, and services in Russia and the new republics.

The scope of activities in Russia and other Eurasian countries includes production,

At the 1992 U.S. Electric Power Technologies Conference (organized by PETC personnel) that was held in Moscow, clean coal technologies were a focal point of the panel discussions. DOE is encouraging the private sector to enter into joint ventures in energy exploration and increased production by working closely with the U.S. Trade Administration, USAID, and the U.S. Department of Commerce. The workshops and technology exchanges that have been held in the past 2 years will assist the Russians in developing new energy production facilities within the context of a market-driven economy. These utilities will be retrofitted or constructed on principles of private ownership, will operate in an economically secure fashion, and will compete in a market-oriented economy. The success of these efforts depends on the partnerships and cooperative efforts that are established between the governments of the countries concerned and the Western investors, the independent energy companies of Russia, and the other former members of the Soviet Union.

A second conference is scheduled to be held in Almaty (formerly Alma Ata), Kazakhstan to acquaint energy industries in Kazakhstan with U.S. business and technologies. The first

conference, held in Almaty in November 1992, emphasized the oil and gas industries (see *PETC Review*, Issue 8, "International Corner: Poland, Kazakhstan, and Russia"); the second will feature the electric power industry. Funded by USAID, the conferences are sponsored by the DOE Office of Export Assistance and are organized by PETC. The U.S. participants for these conferences include senior representatives of interested industries, financial institutions, and the U.S. Government. Kazakhi participants include senior delegates from key ministries and representatives of the appropriate industries and associations. The goals of these conferences are to allow officials to become aware of the needs and capabilities of their respective energy-related industries and to demonstrate to the leaders of Kazakhstan that the U.S. business community has the full support of the U.S. government.

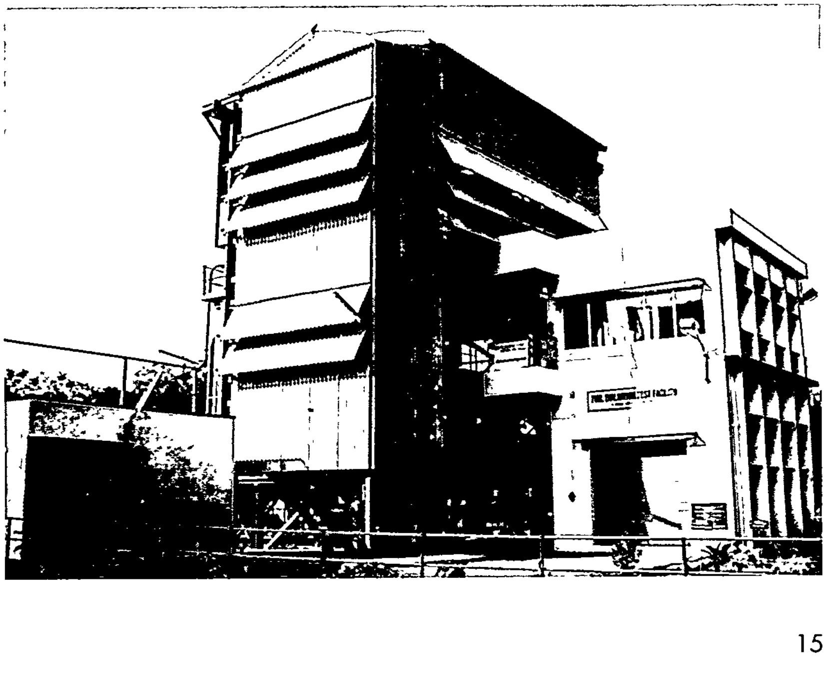
Exporting PETC's Fuels Evaluation Technology

PETC has managed collaborative coal projects in India since 1983. PETC representatives to India provide technical and management coordination for a coal-fired power plant life expectancy demonstration project, coordination with government officials in New Delhi on ongoing and planned coal projects, progress and financial reporting on the PETC USAID agreement, participation in meetings related to coal technology development in India, and information exchange on the status of the U.S. Clean Coal Technology Program (see, *PETC Review*, Issue 9, "International Corner: India").

India is the sixth largest coal-producing nation in the world, but most of its coal has a very high ash content. This presents challenges in both coal cleaning and combustion, as well as in environmental control. In particular, there are large deposits of lignite in India that can be developed to feed the nation's need for electricity generation. However, to use this fuel, India requires information on the combustion behavior of this high-ash, low-energy-content lignite. PETC's Combustion and Environmental Research Facility (CERF; formerly the Fuels Evaluation Facility) is a highly instrumented pilot-scale, coal combustion research facility that simulates the combustion environment of a full-scale utility boiler (see *PETC Review*, Issue 2, "Characterizing Cleaned Coals in PETC's New Fuels Evaluation Facility").

The Indian government, realizing that such a facility would provide the information needed to use their indigenous coal, entered into a cooperative agreement with USAID to build a facility similar to the CERF in India. Ground was broken for the Indian facility (called the Fuels Evaluation Test Facility [FETF]) at Trichy in 1991 using design data based on PETC's CERF. In collaboration with personnel at DOE's Oak Ridge National Laboratory, PETC wrote the specifications for the equipment and instrumentation, all of which were procured in the United States and shipped to India by PETC. The FETF, which is six times the size of the CERF at PETC, was inaugurated in January 1994. PETC will continue to provide assistance to the facility during its start-up period.

The CERF has also been of interest to Korea. Unlike India, Korea has little indigenous fuel and (after Japan) is the world's second largest



India's Fuels Evaluation Test Facility, patterned after PETC's Combustion and Environmental Research Facility, was inaugurated in January 1994. DOE personnel from PETC and Oak Ridge National Laboratory were an integral part of the design and procurement phases of construction. PETC will continue to provide support during the facility's start-up period.

Silhouetted in the background is the Mae Moh Power Plant near Lampang, Thailand, where at the request of the Thais, an EPA Action Team investigated incidents that affected the health and environment of the local population. The EPA, in turn, asked the Office of Fossil Energy to provide assistance, and because of PETC's experience with flue gas control technologies, a member of the PETC staff knowledgable in this area was assigned to work with the team.

importer of coal. Thus, Korea has an interest in examining the combustion characteristics of the coals it must purchase on the world market. PETC is providing technical assistance to the Korea Institute of Energy Research (KIER) to construct and operate a 0.22-MW Fuels Evaluation Facility similar to the CERF at PETC.

PETC's Ties with Thailand

One of PETC's most unusual overseas assignments has been in Thailand. Early in 1993 the Royal Thai Government requested the expertise of a U.S. Environmental Protection Agency (EPA) Action Team to investigate environmental incidents occurring at the Mae Moh Power Plant near Lampang, Thailand. The EPA solicited FE Headquarters to provide an expert in the area of flue gas control technology. Because of PETC's experience in this area, a member of the PETC staff was chosen to accompany the EPA team. The objectives of the action team were to investigate the incidents at the plant associated with adverse health effects experienced by the local population. The team also examined the current monitoring system in the Mae Moh area and made recommendations on appropriate control technology to mitigate the problems.

The Mae Moh complex is quite large and requires about 7,000 employees in the 13-unit power plant. The largest lignite mine in Thailand, Mae Moh produces 30,000 tons (27,000 tonnes) of coal per day. The health and environmental problems in the area include acute respiratory distress among villagers near the plant, noxious smells, and plant and livestock damage. These problems are more acute during the three winter months, especially when periods of inversion may force the plume from the plant toward the ground.

Based on their evaluation of the problem, the action team recommended retrofitting commercially available high-efficiency SO_2 removal equipment on some of the units. Several other units will use moderate-efficiency SO_2 scrubbers. Until these SO_2 removal systems are installed and new boiler units containing their own scrubbers are built, an interim policy has been adopted that reduces plant output during adverse weather conditions.

This episode is an example of interagency interaction to solve problems. It is anticipated that EPA and PETC will cooperate on other occasions in this era of global environmental concern.

Other International Work

In addition to the specific programs described above, PETC personnel are involved in implementing broad-ranging DOE agreements with many other countries. PETC chemists have helped the Chilean government evaluate its coal reserves and have provided consultants for China's fossil fuel research facilities.

These international activities have provided PETC and its personnel with first-hand opportunities to interact with other countries and have familiarized other countries with PETC's capabilities. The Center enjoys and expects to continue in its role as an ambassador of the Fossil Energy International Strategic Plan.

THE 7TH INTERNATIONAL CONFERENCE ON COAL SCIENCE

In 1979, the United States, through the U.S. Department of Energy's (DOE's) Offices of Energy Research and of Fossil Energy joined forces with eight other member nations of the International Energy Agency (IEA) to organize the first International Conference on Coal Science (ICCS). This conference has continued every 2 years and is now recognized as the most prestigious of all conferences dedicated solely to the timely international exchange of basic scientific information on coal.

Under the leadership of Dr. Sun W. Chun, Director of the Pittsburgh Energy Technology Center (PETC), and Dr. F. Dee Stevenson, Program Manager of the Processes and Techniques Branch of the Office of Energy Research Chemical Sciences Division, DOE has been a vigorous supporter of all seven ICCS conferences to date. Conferences have been held in alternating years since 1981, the most recent one having been held in Banff, Alberta, Canada.

Early History

Administration of the ICCS was assumed by the IEA in the late 1970s. The first ICCS was held in Germany in 1981. Pittsburgh, Pennsylvania, was the host city for the 1983 conference, which was organized by PETC and chaired by Dr. Sun W. Chun. Subsequent conferences were held in Australia (1985), The Netherlands (1987), Japan (1989), The United Kingdom (1991), and Canada (1993). The 1995 conference is scheduled for Spain.

Goals, Objectives, and Importance

The ICCS plays an important part in the goals and objectives of the IEA. Founded in 1974 after the energy crisis of 1973, the IEA is the energy forum for 21 industrialized countries. In response to the energy crisis, the IEA's primary mission is to ensure energy security for its 21 member countries. Thus, the role of IEA has a recognizable global impact with respect to a more secure energy future worldwide. Because coal currently provides about 30% of the total world energy requirements and is likely to continue to do so in the next few decades, the worldwide energy community requires an ever-improving scientific and technological understanding of the production and use of coal. The ICCSs were sanctioned by IEA as an essential part of ensuring the development and exchange of that increased understanding.

The ICCS is of great benefit to the United States because it provides an excellent forum for U.S. coal scientists to (1) hear unpublished accounts of current and on-going coal research in all major countries, (2) discuss current research and development activities privately with coal scientists throughout the international coal community, and (3) increase foreign awareness of U.S. technologies and associated products that are available for export. The conferences support both DOE foreign policy and development objectives as well as objectives in science and technology. As part of its foreign policy objectives, DOE supports the IEA and, in particular, is a member of the IEA's Fossil Energy Working Party that authorizes the ICCSs. Jack Siegel, who is DOE's Acting Assistant Secretary for Fossil Energy, currently chairs the Working Party.

Conference Organization and Features

The ICCS is supported by registration fees and contributions made by member nations. Each member nation has at least one representative on the International Organizing Committee (IOC). Drs. Chun and Stevenson have served as the U.S. representatives to the IOC since the inception of the conferences. Host countries for conferences are selected by IOC vote based on proposals submitted by member nations.

The ICCS is primarily a technical conference for the international exchange of scientific information related to coal. Papers are presented by many of the world's most eminent coal scientists, and only unpublished material is accepted for presentation. Most papers are contributed and subjected to three levels of extensive peer review to ensure a quality conference. Papers are first reviewed by a program committee appointed by the host country. These recommendations are then considered by members of the IOC. The final selections and session organization are then delegated to the host-country program committee. Accepted papers may be presented either in oral sessions or as posters. Country membership in the IEA is not required for technical presentations at the ICCS.

Table 1. Member Nations of the ICCS International Organizing Committee

Australia	Netherlands
Canada	Spain
Germany	United Kingdom
Japan	United States

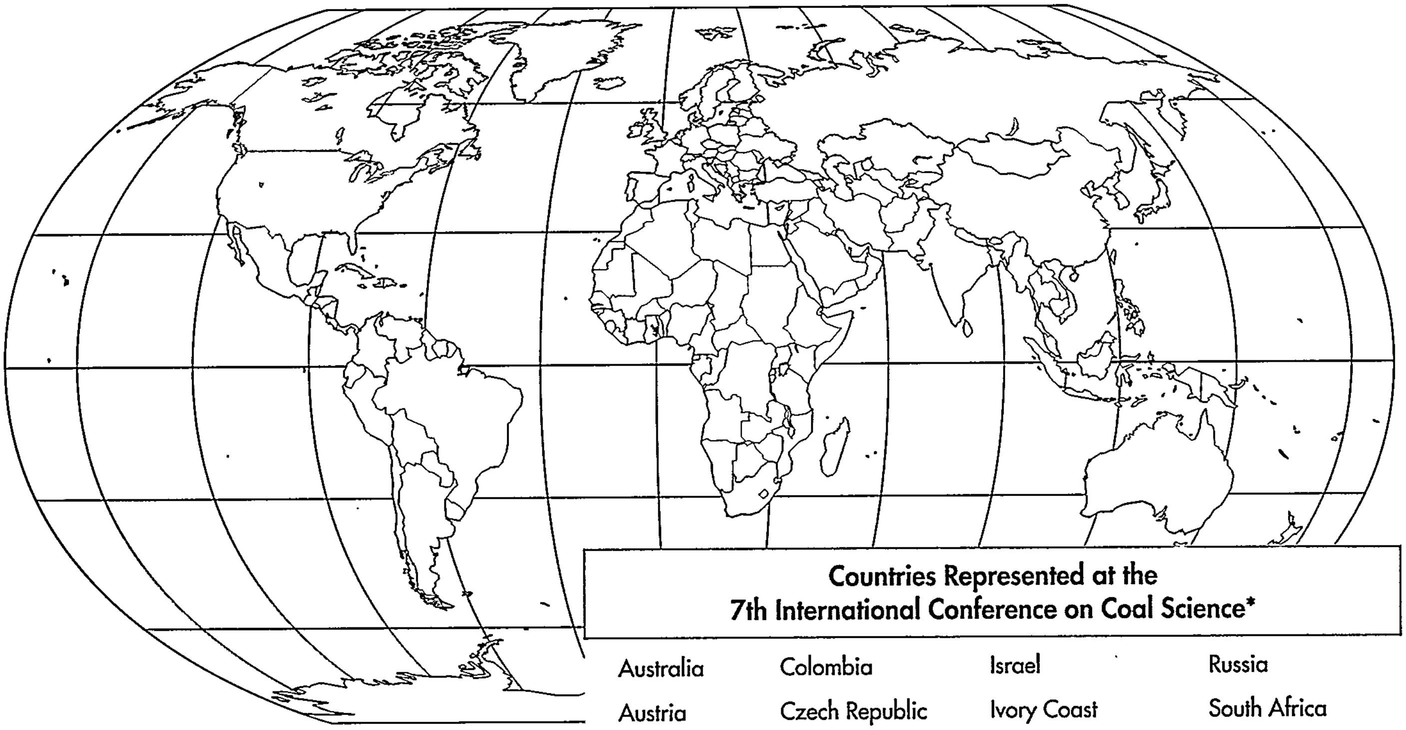
In addition to technical sessions, tours of coal laboratories and coal utilization or conversion facilities are often offered to conferees. A nontechnical program for spouses and guests consisting of local tours of general interest is also made available. Evening activities, both technical and social, are an integral part of the conferences.

Another program feature of the ICCS is the distinguished guest program. Members of the IOC (see Table 1) are encouraged to invite leading coal scientists to attend as special guests of the conference. The presence of these individuals serves to enhance the conference. Guests may serve as resource persons, present papers, or preside at technical sessions. Their most important role, however, is simply to attend the ICCS. Conference attendees seek them out for information on pioneering coal research, encouragement and direction for the attendees' current research activities, and advice on specific technical approaches to problem-solving in coal research.

The 7th International Conference on Coal Science— A Bridge to a Clean Future

The 7th ICCS was held in Banff, on September 12 to 17, 1993. According to one news release, "The best minds in coal science, representing virtually every coal-producing country in the world, participated...." The figure on the following page shows the 22 countries that sent representatives to the conference, attesting to its international status. There were 307 delegates and guests in attendance. Co-hosts for the conference were the Canada Centre for Mineral and Energy Technology (CANMET) and the Alberta Research Council.

To open the conference, several Canadian dignitaries presented welcoming statements. The opening remarks of Sergio Garribba, Director of Energy



Countries Represented at the 7th International Conference on Coal Science*

Australia
Austria
Belgium
Canada
China
Colombia
Czech Republic
Denmark
France
Germany
India
Israel
Ivory Coast
Japan
Mexico
Netherlands
Poland
Russia
South Africa
Spain
United Kingdom
United States

**Countries represented shaded in map above.*

Technology and Research & Development for IEA, deserve special attention. He commented specifically on fundamental coal science and its implications for energy security, coal trade, economic growth, and protection of the environment. Dr. Garribba noted that international cooperation in the energy research and development area, as evidenced by these conferences and other IEA undertakings, has allowed IEA member governments to pool and coordinate their efforts to facilitate the development of new energy technologies and information exchange. He closed by stating, "This conference will offer, I believe, plenty of opportunities for investigation, exchange of information, and new ideas upon which to build a better future for the IEA region and the countries of the world."

The technical program of the 7th ICCS consisted of 144 oral and 177 poster presentations. No area of coal science was neglected, as evidenced by the list of topics in Table 2. Conversion technologies, especially liquefaction, were covered in depth, as was coal combustion. Coal characterization and the use of recently developed characterization techniques, such as nuclear magnetic resonance imaging, X-ray absorption fine structure spectroscopy (XAFS), and atomic force microscopy, received special emphasis. Noncovalent interactions in coal were a principal focus of papers dealing with the intricacies of coal structure because these are thought to be involved during the initial reactions of coal conversion. Pyrolysis and carbonization studies, now largely neglected in the United States, were the subjects of many papers from Europe and developing countries. Technology transfer and the possible exportation of U.S. technology to other countries were often reflected in specific presentations. During the 1970s, PETC was heavily involved in a process designed to remove sulfur from coal using air oxidation. It was learned at the conference that the process, termed oxydesulfurization, is now being explored by the University of Sheffield (United Kingdom) to solve a technical problem that is somewhat unique to coals from the United Kingdom—the presence of large amounts of chlorine that generally leads to boiler corrosion during combustion. PETC experts in the field of oxydesulfurization, in attendance at the conference, were able to offer technical assistance and to encourage the use of U.S. technology overseas.

Table 2. Scientific Topics of the 7th ICCS

- Kinetics of Combustion
- Pyrolysis Kinetics & Mechanisms
- Ignition of Coal
- Pyrolysis Products
- Ash and Slag Characterization
- Coke Formation
- Trace Elements and Minerals
- Liquefaction Catalysts
- Environmental Aspects of Combustion
- Hydrogen Donors in Liquefaction
- SO_2 and NO_x Abatement
- Hydrogen Utilization in Liquefaction
- Greenhouse Effect
- Coalification
- Sulfur, Nitrogen, and Halogens in Coal
- Chemical Composition
- Beneficiation
- Solvent Swelling
- Oxidation and Weathering
- Model Compounds
- Desulfurization
- Analytical, Thermal, and Spectral Techniques

The technical program of the 7th ICCS differed significantly from previous conferences in that increased attention was paid to environmental concerns, thus the theme of the conference: *Coal Science—A Bridge to a Clean Future.* Papers on trace elements in coal and the chemical nature of the sulfur and nitrogen species created much interest. Results of new studies of both the pre-combustion cleanup of coal (beneficiation and desulfurization) and the post-combustion cleanup of flue gases (sulfur dioxide, nitrogen oxides) were presented in several heavily attended sessions.

The environmental technical presentations were complemented by a special two-session workshop entitled *The Role of Scientific Research in Addressing the Critical Environmental Challenges Facing Coal Utilization in the 1990s.* The highlight of the workshop was an evening session featuring Professors Dale Swaine of the University of Sydney and Bill Fyfe of the University of Western Ontario. The brief presentations by Professors Swaine and Fyfe were followed by much longer and more extensive question and answer periods.

Professor Swaine's presentation focused on trace elements. He prophesied that many trace elements "are destined to receive the critical attention now accorded sulfur oxides, nitrogen oxides, and carbon dioxide." He downplayed the role of modeling studies, emphasizing that the factors that influence how the elements interact with the air, soil, plants, and water that eventually absorb them vary dramatically from site to site. His closing remarks, although given in regard to the environmental effects of trace elements, are important in a much broader sense: "Society needs realism, good sense, and balance through science. The world can have conservation in equilibrium with development if scientists do good research and obtain the good will of society and industry. This will happen through the building of trust."

Professor Fyfe's remarks were more general and included personal thoughts related to population growth, greenhouse gases, energy conservation, methods of pollution control, and the general relationship between countries with the longest average life span and their energy availability. He projected that fossil carbon, solar, and geothermal would be the energy sources for the next century, and stated emphatically that "there is no shortage of energy for the future, nor of potential technology to make that energy available."

If you would like additional information on the International Conference on Coal Science, please contact:

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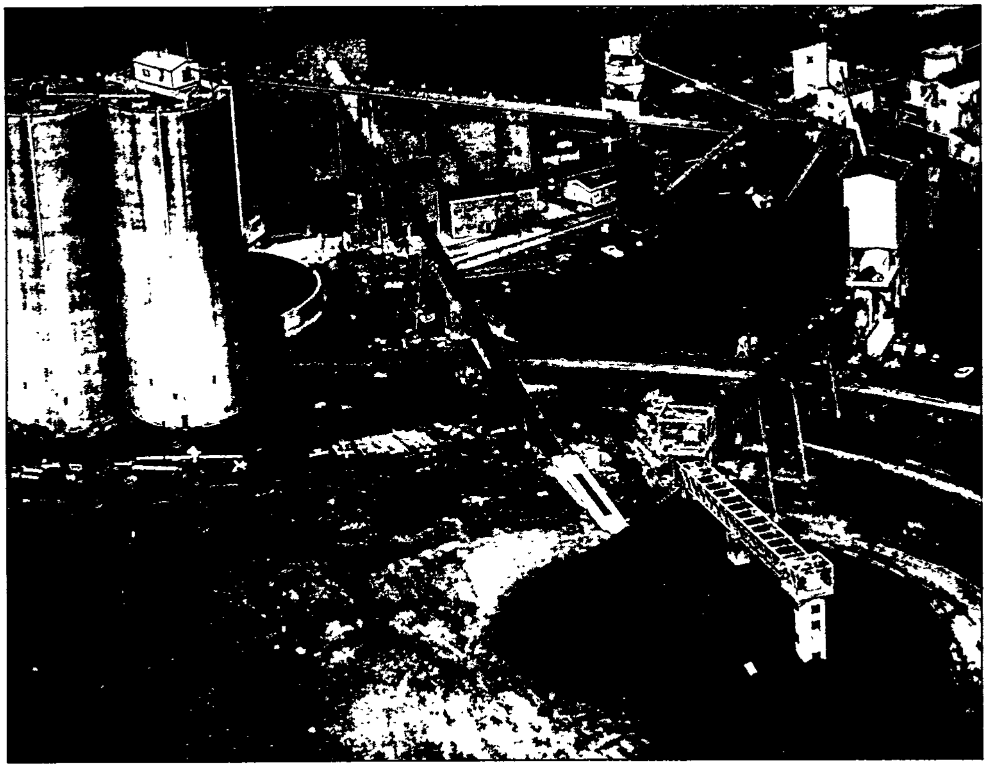
UPDATE

Near-Term Testing of Advanced Physical Coal Cleaning Technology

PETC research coming to fruition.

Estimates show that as much as 10 to 20% (by weight) of current coal preparation plant throughput is fine material. This material is often discarded as refuse because of the inefficiencies of conventional cleaning and dewatering equipment in processing fine coal. Advanced physical coal cleaning processes being developed for producing premium fuel (i.e., ultraclean coal in which the sulfur and ash contents have been significantly reduced) for advanced power systems require that the coal be finely ground. Therefore, an opportunity exists for the early application to new or existing coal preparation plants for the purpose of economically and efficiently cleaning coal fines.

As part of a cost-sharing program sponsored by DOE/PETC, Amax Research and Development Center (now part of Cyprus-Amax Coal Company), recently completed an engineering analysis and feasibility study of the potential near-term use of advanced coal cleaning technology for processing coal fines at three of their plants—Ayrshire in Indiana, Lady Dunn in West Virginia, and Wabash in Illinois. The integration of the advanced processes into the preparation plants' existing cleaning circuitry was evaluated on a conceptual design basis. The analysis concluded that near-term application of advanced fine-coal cleaning technology could (1) increase the recovery of clean-coal product, thereby increasing overall plant revenues at a nominal increase in operating costs and (2) reduce the volume of waste material produced by the plants.



The Wabash Coal Preparation Plant, Keensburg, Illinois, is a newly constructed facility under consideration for near-term testing of advanced technologies for processing coal fines.

The Ayrshire plant was subsequently dropped from consideration because the mine feeding the plant will be shut down for an extended period of time. Laboratory tests with coals from the remaining two plants will be conducted to verify the study results. Both the newly constructed 1,500-ton-per-hour (1,350-tonnes-per hour) Wabash Preparation Plant (see photograph) located near Keensburg, Illinois, and the Lady Dunn plant in West Virginia are being considered for near-term testing.

WHAT IS COAL?

Coal, the largest tonnage commodity produced in the United States, is also one of the least understood. It is often described as a black rock composed of amorphous carbon, formed by transformations of organic material requiring tens to hundreds of millions of years. This description of coal is misleading and fails to present a true picture of the nature and complexity of coal, its composition, and its formation. What, then, do we really know about coal?

Coal is Black

This is the most obvious characteristic of coal, yet it is surprisingly inaccurate. Even to the naked eye, a lump of coal displays areas with different visible surface features. Some areas are shiny, others appear dull. Occasional fragments of minerals can be seen. In many coals, gold-colored particles of pyrite or "fool's gold" (FeS_2) or white to yellow powder particles of air-oxidized pyrite are discernible. All of these hint at how colorful and varied coal appears when viewed in thin sections under a microscope in transmitted light. Microscopic examination reveals the truly heterogeneous nature of coal (see Figure 1). At a magnification of 40–60x, coal exhibits brilliant colors—yellow, orange, red, brown—which result from the different components that make up coal. Inorganic mineral intrusions, mostly alumino-silicate clays and pyrite, do not transmit light and, therefore, appear as opaque particles under the microscope. The colored sections represent the major organic portion of coal. But even that part is far from uniform. The organic portion of coal is classified into three distinct constituents, called macerals, mainly on the basis of differences in microscopic light reflectance. Each of the macerals, in addition to microscopic differences, exhibits different physical and chemical behavior and is derived from different precursors.

Figure 1. Thin sections of coal viewed under a microscope reveal the heterogeneous components that make up coal.

Because these macerals tend to be intimately mixed, even at the microscopic level, it is difficult to obtain pure samples. By careful hand-sorting of small particles of coal (under a microscope), it has been possible to obtain almost pure samples for examination. Concentrates of macerals are also prepared by taking advantage of the small differences in their densities.

By far the most abundant maceral in most U.S. coals is vitrinite, representing as much as 85% of the organic portion. Under the microscope in transmitted light, the vitrinite varies in color from yellow-orange to orange, red, and brown and even becomes opaque as the rank of coal increases (see sidebar p. 23). The vitrinite provides the defining behavior of a coal, especially its chemical reactivity. Usually, a reference to a property of coal means the property of the vitrinite maceral.

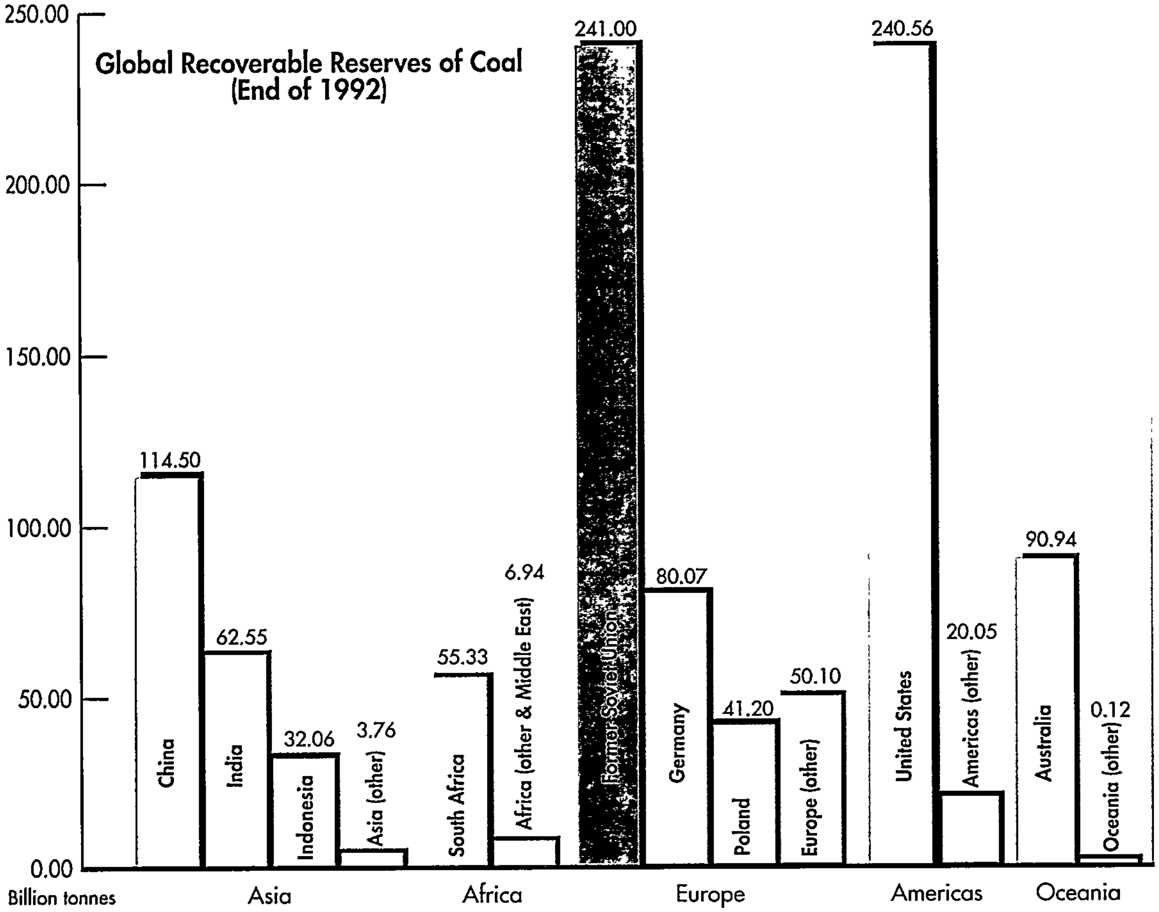


Figure 2. 1992 Global recoverable coal reserves by geographic region for countries with the largest reserves.
Source: 1993 BP Statistical Review of World Energy.

The second colorful component of coal is the exinite or liptinite. This maceral, usually only several percent by weight of a coal, occasionally is present in much larger amounts, especially in some coals found outside of the United States. In transmitted light, the exinite usually appears yellow. It is made up of inclusions of organic material from the coal precursors and is derived largely from spores, resins, waxes, etc., that have undergone little or no metamorphosis in the coalification process. Much of the exinitic material is readily soluble in organic solvents and can be extracted from coal. Within this extract, naturally occurring organic compounds, or biomarkers, are found that relate coal to its precursors. Among these biomarkers, the most obvious are several terpene hydrocarbons characteristic of plants.

The third maceral in coal is inertinite, a designation that accurately describes its behavior. It is opaque to transmitted light, although bright in reflected light. The inertinite is thought to be the charred remains of the plant precursors of coal, perhaps the debris of fires, and is incorporated into the coal-forming mass without further conversion. Inertinite accounts for only several weight percent of a coal.

From the Arctic to Antarctica

Coal is found in areas throughout the land mass of the earth and can even be found undersea along some seacoast regions. It exists in areas from the Arctic Circle to Antarctica and is mined in widely dispersed areas of all the continents except Antarctica (see Figure 2). In some areas, such as the Illinois basin of the United States, a number of extensive deposits, or seams, of coal are found one above the other, each with different properties. In these instances, the deepest coal bed generally is the oldest and of the highest rank, with each successive bed being younger and lower in rank.

In the United States, extensive coal beds are found along both the eastern (Appalachian) mountain range and the western (Rocky) mountain area. In addition, large deposits exist in the central states and the Northern Plains. Other smaller deposits are found in several other areas (see Figure 3).

Coal is Amorphous Carbon

The concept that coal is merely an amorphous, or non-crystalline, allotrope of elemental carbon survived until 50 to 60 years ago and is still accepted by those unfamiliar with the molecular structure of coal. In reality, coal is best described as a macromolecular matrix consisting of an apparently random aggregation of monocyclic and polycyclic aromatic and heteroaromatic ring systems, substituted by phenolic-OH groups and alkyl (mostly methyl) side chains, and interconnected by a variety of covalent and hydrogen-bonding linking groups. Rather than being an amorphous elemental carbon, coal has considerable functionality and organic structure. Although a molecular weight range is occasionally quoted for coal, these values apply only to the fragments obtained by chemical or thermal cleavage of bonds within the macromolecule or to the soluble extracts. The true extent of molecular bonding in coal is unknown.

Because coal is a metamorphosed degradation product of an initially complex biological precursor, it has no single unique molecular structural unit. Although a coal sample may contain more than one repetition of a structural unit (e.g., benzene, naphthalene, or phenanthrene ring system), that unit is believed to have different groups randomly connected to it all or most of the time. However, average molecular parameters have been derived from a variety of chemical and spectroscopic measurements. For instance, we can measure the ratios of the structurally inherent elements—carbon, hydrogen, oxygen, nitrogen, and sulfur—in a coal sample. From a combination of infrared and nuclear magnetic resonance measurements, we can determine the ratio of aromatic to aliphatic carbon and hydrogen. Several chemical methods are available to estimate the percentages of oxygen present as phenolic and carboxylic groups—most of the remainder of the oxygen is regarded as present in ether groups. All of these gross structural data lead to an "average" chemical structure for any given sample of coal (see sidebar p. 21). This average structure does not represent any real coal molecular segment, only the structure of a hypothetical segment. Although sometimes useful in speculating about the properties or behavior of coal, these "average" molecular structures can be misleading when they are invoked as "real." Because no two coals are identical, no two coal "structures" are alike.

Compounding the problem of describing the structural complexity of coal is the presence of material soluble in organic solvents. The

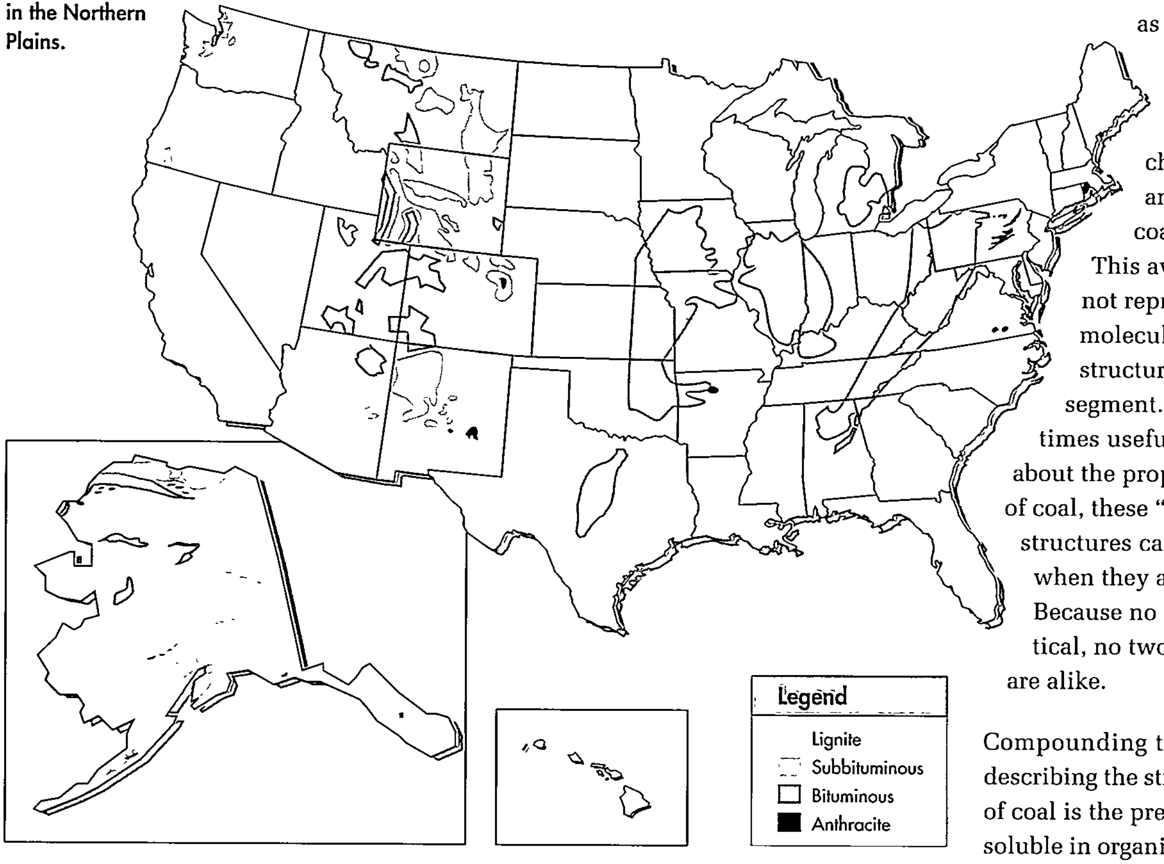
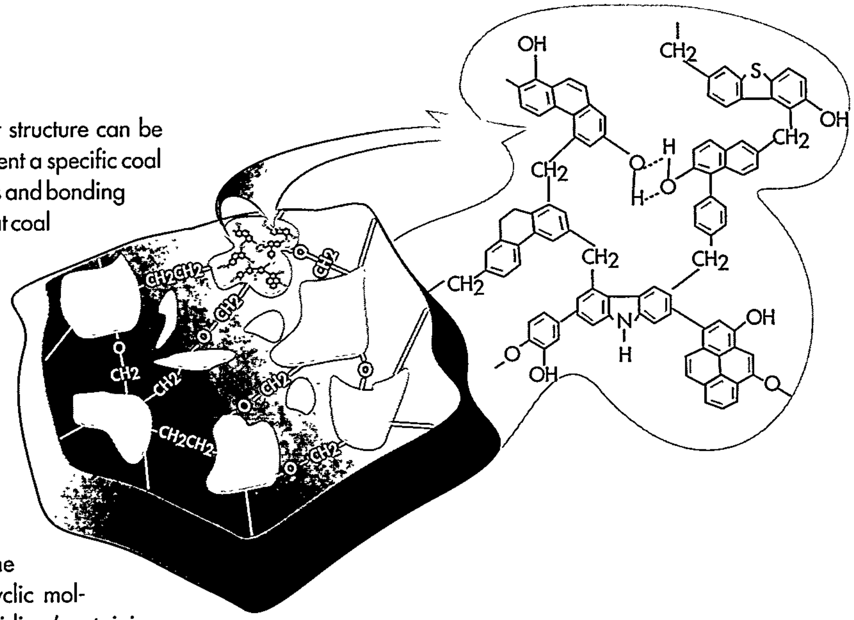


Figure 3. Coal of various rank is found in 38 of the 50 states, with extensive deposits found along the Appalachian and Rocky mountain ranges. Large coal beds are also found in the central portion of the country and in the Northern Plains.

AN "AVERAGE" STRUCTURE OF COAL

For any sample of coal, only an average molecular structure can be derived. The structure shown is not intended to represent a specific coal sample; it merely illustrates the types of molecular units and bonding believed to exist in coals. The lower figure indicates that coal is made up of both small molecules (shown in gray) that can be readily dissolved and of larger molecules made up of units (shown in orange) that are covalently bonded together to form the macromolecular (very large molecule) matrix that is the principal coal structure. The upper figure shows some of the smaller molecular structures and types of bonding that are present in coal. Included are benzene (6-carbon hexagonal molecule), naphthalene (10-carbon bihexagonal molecule), phenanthrene (14-carbon trihexagonal molecule), pyrene (14-carbon tetrahexagonal molecule), the heterocyclic molecules dibenzothiophene (containing sulfur) and acridine (containing nitrogen), phenolic groups (–OH), methylene linkages ($-CH_2-$), ether linkages (–O–), and hydrogen-bonded, weak linkages (–O----H–O). (*Note:* Not all hydrogen atoms bonded to ring carbons are shown.)



Above, an "average" coal structure, as depicted by Dr. Sid Friedman, *PETC Review* Senior Technical Editor.

amount of soluble material varies from less than 1% for extraction by a "poor" solvent, (e.g., hexane) to more than 20% by a "good" solvent (e.g., pyridine). Solubility also varies from coal to coal, and there is some correlation to rank or carbon content. The maximum amount of soluble material is found in coals with a carbon content of about 87%. Although some of the soluble fraction is associated with the liptinite (e.g., waxes and resins) and is made up of relatively small, unassociated soluble molecules, much of the material dissolved by "good" solvents is apparently widely dispersed throughout the coal (i.e., vitrinite) either in micropores or encapsulated within the macromolecular matrix. "Good" solvents swell the coal matrix, making these trapped molecules accessible to the solvent. Gas chromatographic-mass spectrometric analysis of these extracts indicates that they are made up largely of aromatic and heteroaromatic compounds of one to four rings, including phenolic and aliphatic substituents, as well as other unidentified molecular species. The similarity between the structural features of the soluble molecules in the extracts and the average structural parameters lends credence to the assumption that these soluble molecules are representative of the types of units or subunits in the macromolecular matrix. Unanswered questions about these soluble fractions include:

(1) How closely related structurally are these soluble molecules to the rest of the coal matrix?

(2) Are these molecules precursors of the macromolecular matrix or fragmentation products of it?

(3) How important are these molecules in defining the reactivity of coal, as in liquefaction?

Just as the organic chemist has a variety of chemical molecular "structures" for coal and the microscopist has pictures showing the microscopic nature of coal, the physical scientist provides data to quantify the physical characteristics of coal. There is a strong indication that coal is formed by the layering of its biological precursors, as expected from its proposed origin. This "layering" extends even to the molecular level, as indicated by X-ray diffraction examination. At the lowest coal ranks, the layers are small in size, and there is considerable randomness in orientation. With increase in rank, the layers in a stack increase in dimension as well as number, and they become more

IT STARTED WITH COAL

Coal research and technology is not thought to result in "spin-offs," but there are some notable examples. Perhaps the most dramatic is the result of research into coal liquefaction.


© The Nobel Foundation

Friedrich Bergius

In 1913, Friedrich Bergius of Germany announced that he had succeeded in converting solid coal into a liquid resembling petroleum, from which he was able to distill a product suitable for use as gasoline. The process, subsequently called the Bergius process, used elevated pressure (up to 4,000 psi, or 27.6 kPa) and heat to treat powdered coal with a catalyst in the presence of a liquid vehicle and hydrogen gas. This was one of the first technological uses of elevated pressure chemistry and the first that required handling liquids under such high pressures.

Because Germany, which had ample supplies of coal but no petroleum, desired self-sufficiency in gasoline, development of the Bergius process received considerable support during the next three decades. This process, requiring large-scale high-pressure equipment, provided much of the incentive for developing the apparatus necessary for commercialization. Pumps, valves, and reactor vessels capable of handling the high pressures needed for the chemical transformation were designed primarily for coal hydrogenation.

Although industrial-scale processing of coal for direct liquefaction has been limited to production of synthetic fuels in Germany during World War II, the technology for high-pressure chemistry of liquids had its beginning in coal liquefaction.

In 1931, Friedrich Bergius received the Nobel Prize in Chemistry (shared) for his pioneering work in coal liquefaction.

orderly in orientation along an axis. The highest rank coals approach graphite in structure, having extensive, flat, stacked layers of polycyclic aromatic structures.

Another physical attribute of coal is porosity, including the accessible pore surface area. Measurements of pore volume or surface area for coals provide a wide range of values depending on the coal and the method used to make the measurement. Surface areas of coals vary from <1 m^2/g when measured by N_2 adsorption to 200–400 m^2/g when measured by CO_2 adsorption. The high CO_2 adsorption values may result from dissolution of the CO_2 in the coal instead of the monomolecular surface coverage that is assumed by this method. The extremely low surface areas indicated by N_2 adsorption for some coals are actually less than the exterior surface areas of the particles. True surface areas must be somewhere in between.

Pore volume measurements also produce a diversity of results. As expected, these vary according to coal and method of measurement but not with the range shown for surface area. The general picture that emerges is that less than 10 to 30% of a coal may be pore volume and that pore sizes vary from micropores (2 nm or less in diameter) to macropores (more than 20 nm in diameter). The percentage of pore volume present as micropores increases irregularly as the rank of the coal increases. Only in lignites are the macropores the dominant variety.

Coal Was Formed from Decayed Plant Material over Tens to Hundreds of Millions of Years

Although there is almost universal agreement that coal is derived from once-living vegetation, the time frame for its formation is debatable. The vegetative origin of coal has been established based on (1) the quantities and ratios of carbon, hydrogen, oxygen, and nitrogen in coal; (2) the presence of the biomarkers, spores, and other plant-derived liptinitic material; (3) the observation of still-existing, plant-like cell wall structures in some vitrinite samples; and (4) the chemical resemblance of lignite to plant lignin, as well as the assumed role of plant-derived peat as a precursor of coal.

The amount of time it takes coal to form is, however, open to another interpretation. The plant material from which coal is derived was deposited during geological time periods from the Devonian period of the Paleozoic Era (about 360 million years ago) until the Tertiary period of the Cenozoic Era (about 30 million years ago). The most extensive coal deposits date from the Carboniferous period of the Paleozoic Era (about 300 million years ago). This was a period of plant growth that was encouraged by a warm, moist climate. The plant life flourished, then died, forming dense deposits of decaying material in swampy conditions. Under the water, anaerobic microorganisms assisted in the process of converting the plant debris into a peat-like deposit, incorporating mineral matter from the environment and unconverted (e.g., spores, waxes, resins) and partially converted plant material.

RANK

Exposed coal seams in Healy, Alaska, near one of PETC's ongoing Clean Coal projects. The deepest coal seams are generally the oldest and of the highest rank.

All coals are not the same. In fact, no two samples of coal are identical, either at the molecular or macroscopic levels. Coal deposits worldwide show variations in many properties that range over wide limits. As a convenience in correlating coals according to properties, coal has been classified by rank—an arbitrary system based initially on fuel value and metallurgical (coke-forming) properties and designed for commercial interests. Fortunately, many coal properties are interrelated, so that classification by rank simultaneously orders coals roughly in the ascending or descending order of these properties. In ascending order of rank (peat, lignite, subbituminous, bituminous, anthracite), the coals exhibit a regular increase in percentage of carbon (with consequent decrease in hydrogen and oxygen contents), an increase in energy content, an increase in vitrinite reflectance, an increase in aromatic molecular complexity, and a decrease in functional group content. (Peat is not usually included in the ranks of coal, although it represents the initial stage in coal formation.)

Because the deposits were formed millions of years ago, it has been inferred and often stated that 300 million years were required to transform that plant material into today's coal deposit and, as a corollary, that each deposit was transformed gradually (matured) during that time to coals of progressively higher (or older) rank. This helped to explain the rather rough correlation between geological age and rank of many coal deposits: the older the coal, the higher the rank. However, there are many exceptions to this generalization and an equally logical, alternative explanation.

We know that the plant material differed by location and by geological periods. The factors responsible for the ultimate properties of the pre-coal deposit (e.g., salinity and pH of the wet environment, the microorganisms present during the composting period, the temperature of the area) were probably different in each of the locations where coal ultimately formed. These differences, combined with the variations in plant material, probably led to the variability among coal-precursor deposits. These differences in progenitor may be responsible, at least in part, for the variations in rank among coals.

The process of peat forming from decaying vegetation is occurring throughout the world's swamplands, including the Florida Everglades, pictured above. ***Photo courtesy of the National Park Service.***

The two principal parameters believed to be responsible for the variability among coals, particularly rank, are the pressure of overburden experienced during metamorphosis and the temperature extreme to which the deposit had been subjected. Although these factors undoubtedly have played an important role in the degree of metamorphosis of a coal, the metamorphosis may not have required the entire length of time indicated from the formation of the deposit to the present. In other words, it is not necessarily true that (1) a coal seam that is 300 million years old required all 300 million years to become the coal that it is today or (2) that the subbituminous coal of today will ever become the bituminous coal of tomorrow.

A likely scenario is that the decaying vegetation was converted into peat, a partially decomposed residue. This process is occurring worldwide today in swampy areas (e.g., the Okefenokee Swamp in Georgia and Florida and the Everglades in Florida) although the vegetation of the coal-forming eras was different from the growth found today in our swamps. After sediment formed and covered the peat bed, it would have been transformed into its ultimate coal type by one or more geological processes, such as the movement of tectonic plates and the uplifting of strata to form mountains, or by the accumulation of large amounts of sediment. These events would provide the pressure from the overburden and the heat that results either from the geological event or from the thermal gradient because of burial depth—the two geological parameters believed to be the major factors in determining rank. Regardless of when the peat deposit had been formed or of how long it had been buried, the geological events responsible for converting the deposit to coal determined the rank and characteristics of the coal. Thus, the 300-million-year-old peat deposit was probably converted to bituminous coal during one or more "short" geologic time events and has remained such ever since. It did not require 300 million years of burial to be converted.

The vitrinite in coal probably arises from the transformation of the lignin of the plant material. In low-rank coals—peat, lignite, and some subbituminous coal—the vitrinite shows strong similarities in chemical structure to lignin. Both contain long chains of monocyclic aromatic rings and considerable oxygen functionality in the form of phenols and ethers. We assume that during the early biogenetic phase of coal formation, the more easily degraded cellulosic plant constituents were destroyed, leaving the more resistant lignin to form the vitrinite during geological metamorphosis.

This assumption explains the origin of vitrinite in low-rank coals but does not adequately fit the evidence for high-rank vitrinites. As one ascends the rank of coal, the vitrinite becomes more polycyclic in aromaticity and lower in oxygen functionality, ultimately approaching a graphitic structure in the highest ranking coal. Traditionally, this alteration has been ascribed to the effects of a longer period of metamorphosis and of deeper burial with consequences of higher temperatures and greater pressures of overburden. However, lignite structures appear to be more thermally stable than cellulose, which readily transforms into coal-like chars when heated. These cellulose-derived chars are polycyclic in character and exhibit some physical properties similar to high-rank bituminous coal. This behavior, admittedly not comparable to the geological process, does raise the possibility that, although low-rank coal (especially lignite) was formed from lignin, the higher rank coals may have been formed, in part, from cellulosic plant debris that was not completely degraded by microorganisms.

What, then, do we know about the origin and nature of coal? We know—

- when the peat-like deposits of decaying vegetation that ultimately formed coal were laid down,
- that coals have complex chemical structures,
- that all coals are not the same,
- that coals are non-uniform mixtures of components, and
- that coals are porous and layered and display vivid colors through thin sections in transmitted light.

Because of its heterogeneity and variability, many characteristics of coals are not understood. Little is known about the chemical nature of the heteroatoms (S, N, O) in coal or about the bonding between atoms that holds the macromolecular matrix together. Too often, experiments result in conflicting or inconsistent evidence. The challenge of solving the problems relating to the nature and behavior of coal has led to the development of new techniques, many of which find applications in totally unrelated uses. In its unusual and unglamorous way, coal research provides an unrecognized "scientific frontier."

FOCUS ON

PETC employees who make a difference

Kay Downey

As Technology Transfer Officer at PETC, Kay Downey works with industry to encourage use and commercialization of technologies developed by government and government-funded research. An early proponent of the benefits of Cooperative Research and Development Agreements (CRADAs), she was instrumental in developing PETC's initial CRADA in 1989, which was the first in the DOE system.

Kay has been an active participant in the Federal Laboratory Consortium (FLC) for Technology transfer and, in November 1993, was elected to a 2-year term as Deputy Regional Coordinator for the five-state (plus the District of Columbia) Mid-Atlantic Region. Last spring, she served as program chair for the FLC National Technology Transfer Meeting in Pittsburgh, which attracted more than 500 attendees.

In response to a developmental opportunity from the Assistant Secretary for Fossil Energy in the spring of 1993, Ms. Downey was nominated to take part in a 2-month assignment in the DOE Headquarters Office of Technology Utilization. Her assignment, as a member of a working group drafting the Secretary's Strategic Plan for Technology Transfer, included direct participation in policy analysis and development. While in Washington, DC, Kay gained an increased awareness of Headquarters operations and participated in the actions and activities set forth under the Secretary's plan. She attended congressional hearings and assisted in preparing material for congressional testimony and staff briefings. During this assignment, Kay met with senior staff of the Office of the Secretary, attended relevant professional society meetings and conferences, and met with private-sector representatives to review, analyze, and offer responses to the broad spectrum of actions handled by the Office of Technology Utilization. The Director of the Office of Technology Utilization, Roger A. Lewis, wrote, "Her insights into the realities of the laboratory-partner negotiations process were particularly helpful throughout the assignment. It is important to note that developmental assignments work both ways. Kay is a patient and effective teacher. One of our objectives from the developmental assignments was to gain a better appreciation for field activities and government-owned, government-operated laboratories... we have greatly benefited from her knowledge and perspective."

After serving with the Secretary's Strategic Plan Working Group, Kay returned to PETC and started implementing the actions outlined in the plan to increase stakeholder input in the Department's activities. In October 1993, Kay arranged PETC's first Partner Feedback Meeting, which was attended by 40 industry and university participants. More than a dozen PETC and Headquarters personnel were involved as facilitators and presenters. To obtain an even broader view, questionnaires were sent to contractors, CRADA participants,and other customers, including unsuccessful proposers. Ideas generated were discussed at the National Partners Feedback Meeting in November 1993, in Washington, DC.

PETC's future activities in the international energy field will, among other things, necessitate the increased transfer of technologies to help emerging democracies overseas as they retrofit and environmentally upgrade their older coal-fired utilities. Kay states, "We need a different mind-set if we're going to deal with industry and market the results of PETC's R&D worldwide. A good technology, a 'better mousetrap' if you will, is not a guarantee of success. Does anybody know about it? Does it compete here and offshore? Is it what the customer needs and, very important, is it affordable? We in the government have to cultivate an international marketing perspective if we expect to help the United States be strong in a global market."

Kay Downey

NO_X REDUCTION BY SCR/SNCR

As a precursor to acid rain and a contributor to ozone formation, nitrogen oxides (NO_X) emissions are likely to be targeted for further reduction by the U.S. Environmental Protection Agency (EPA) when it sets new regulatory standards on annual average allowable emissions. Consequently, renewed focus has been placed on NO_X controls, which may be required to meet new compliance standards.

Beginning in 1995, the EPA will establish standards for all tangentially and wall-fired boilers. The EPA will also establish new NO_X emission limits for all other categories of boilers (i.e., wet bottom, wall-fired boilers; cyclone boilers; units applying cell burner technology; and all other types of utility boilers) by January 1, 1997. Setting these benchmarks will take 2 years because different boiler system designs cause the formation of differing amounts of NO_X. In addition to boiler system design, other variables that affect the generation of NO_X are flame temperature, residence time at high temperature, quantity of excess air available for combustion, and nitrogen content of the coal being burned. The greater any of these variables, the greater is the tendency to form NO_X. Because so many variables are involved in NO_X formation and because the process for reducing NO_X emissions must not create any other hazardous air pollutants, there cannot be one standard method for controlling NO_X emissions from existing plants. The EPA has stated that the cost of implementing a retrofit technology will be balanced against its benefits. Therefore, when EPA creates new emissions standards, they will be based on the best existing system of continuous emissions reduction, the control technologies available, the cost of the available technologies, and collateral environmental impacts of using the control technologies. Through the Pittsburgh Energy Technology Center (PETC) Clean Coal Technology (CCT) Demonstration Program, the U.S. Department of Energy (DOE) is co-sponsoring the demonstration of retrofit technologies that provide low-cost alternatives for reducing NO_X emissions from existing coal-fired utility boilers. In general, there are three principal retrofit technologies that reduce NO_X emissions. The first two methods, advanced overfire air and reburning, have already been discussed in previous issues of the *PETC Review* (see Issue 6, "Low-NO_X Combustion Retrofit Projects," and Issue 9, "Reburning for NO_X Reduction"). This article focuses on the third method, Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) and also reviews several ongoing CCT demonstration projects that will help define SCR/SNCR's role in regulatory compliance strategy.

The Selective Catalytic Reduction Process

SCR technology involves the injection of ammonia (NH_3) into the flue gas passing through a catalyst bed where NO_X and ammonia react to form harmless nitrogen and water vapor at economizer exit flue gas conditions (typically about 700°F [370°C]) prior to particulate removal. The quantity of NH_3 needed for a particular boiler system can be computed from measurements of the uncontrolled NO_X emission, the assumed amount of NO_X reduction achieved through combustion modifications, and the estimated compliance target for NO_X reduction. Under typical SCR design and operating conditions, NO_X reduction efficiency is directly proportional to the NH_3:NO_X ratio up to NO_X reduction levels of about 80%.

A simplified flow diagram for a typical SCR process installation at a pulverized coal power plant whose design includes a "cold-side" (i.e., post air-preheater) electrostatic precipitator (ESP) is depicted with major equipment in Figure 1. Hot flue gas leaving the economizer section of the boiler is ducted to the SCR reactor. Before the flue gas enters the gas stream, ammonia (NH_3) is injected into the gas stream sufficiently upstream from the SCR reactor to allow complete mixing of the NH_3 and the flue gas. The quantity of NH_3 is adjusted to achieve the desired degree of reaction with the NO_x from the flue gas as the gases pass through the catalytic bed of the reactor. The flue gas leaving the reactor passes through the air preheater where it transfers heat to the incoming combustion air. Provisions are made for removing some of the expected fly-ash fallout from the bottom of the reactor. Ductwork is also installed to bypass some flue gas around the economizer during periods when the boiler is operating at reduced load. This is done, especially on retrofits, to maintain the temperature of the flue gas entering the catalytic reactor at the proper reaction temperature. When required, sodium- or calcium-based absorbents for SO_2 removal can be injected into the flue gas as the flue gas exits the air preheater to the boiler's particulate removal device.

Figures 2 and 3 provide additional details about the catalyst configuration and installation in a typical commercial application of SCR. Catalyst elements are manufactured using a mold/extrusion process and form the fundamental building blocks of SCR installations. Catalyst elements are offered commercially in two basic geometric shapes: honeycomb grid and plate. Several catalyst elements are bundled together to form a catalyst module. Commercial installations use multiple modules in several layers to form a commercial SCR reactor. Current formulations of SCR catalyst, based on processes patented by the Japanese, typically employ vanadium pentoxide (V_2O_5) as the active material deposited on or incorporated into a substrate. Although SCR is successfully and widely practiced in Japan and Western Europe to meet stringent NO_x emission regulations, numerous technical uncertainties are associated with applying SCR to U.S. coals. These uncertainties include:

- Potential catalyst deactivation resulting from poisoning by trace metal species present in some U.S. coals that are not present or present at much lower concentrations in other fuels.

- Performance of the technology and effects on the balance-of-plant equipment in the presence of high amounts of SO_2 and SO_3 (e.g., plugging of downstream equipment with ammonia-sulfur compounds caused by unreacted ammonia leaking through the SCR reactor or "ammonia slip").

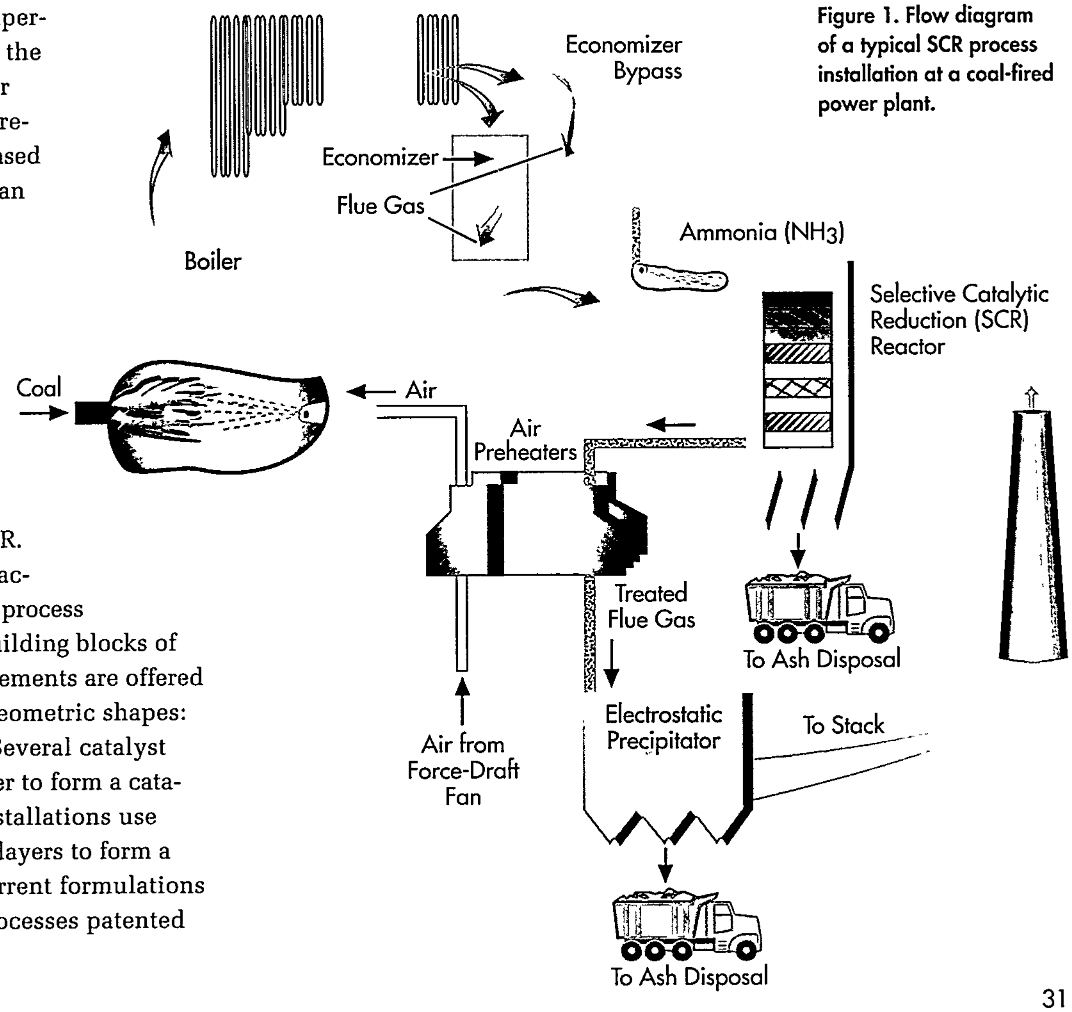


Figure 1. Flow diagram of a typical SCR process installation at a coal-fired power plant.

- Performance of a wide variety of SCR catalyst compositions, geometries, and manufacturing methods under typical high-sulfur, coal-fired utility operating conditions.

These uncertainties are being explored by constructing a series of small-scale SCR reactors and simultaneously exposing different SCR catalysts to flue gas derived from the combustion of high-sulfur U.S. coal. The first and second uncertainties will be examined by evaluating SCR catalyst performance for 2 years under realistic operating conditions found in U.S. pulverized coal utility boilers. Deactivation rates of the catalyst exposed to the flue gas from high-sulfur U.S. coal will be documented to determine catalyst life and associated process economics. The second uncertainty will be explored by performing parametric tests with the installation and operation of air-preheaters downstream from the larger SCR reactors. During the parametric tests, SCR operating conditions will be adjusted above and below design values to observe NO_x reduction performance and ammonia slip as functions of the change in operating conditions. Air-preheater performance will be observed to evaluate the effects of SCR operating conditions on heat transfer and boiler efficiency. The third uncertainty is being addressed by using honeycomb- and plate-type SCR catalysts of various commercial compositions from the United States, Japan, and Europe. Results from the tests with these catalysts will expand the performance knowledge of a variety of SCR catalysts under U.S. utility operating conditions with high-sulfur coals.

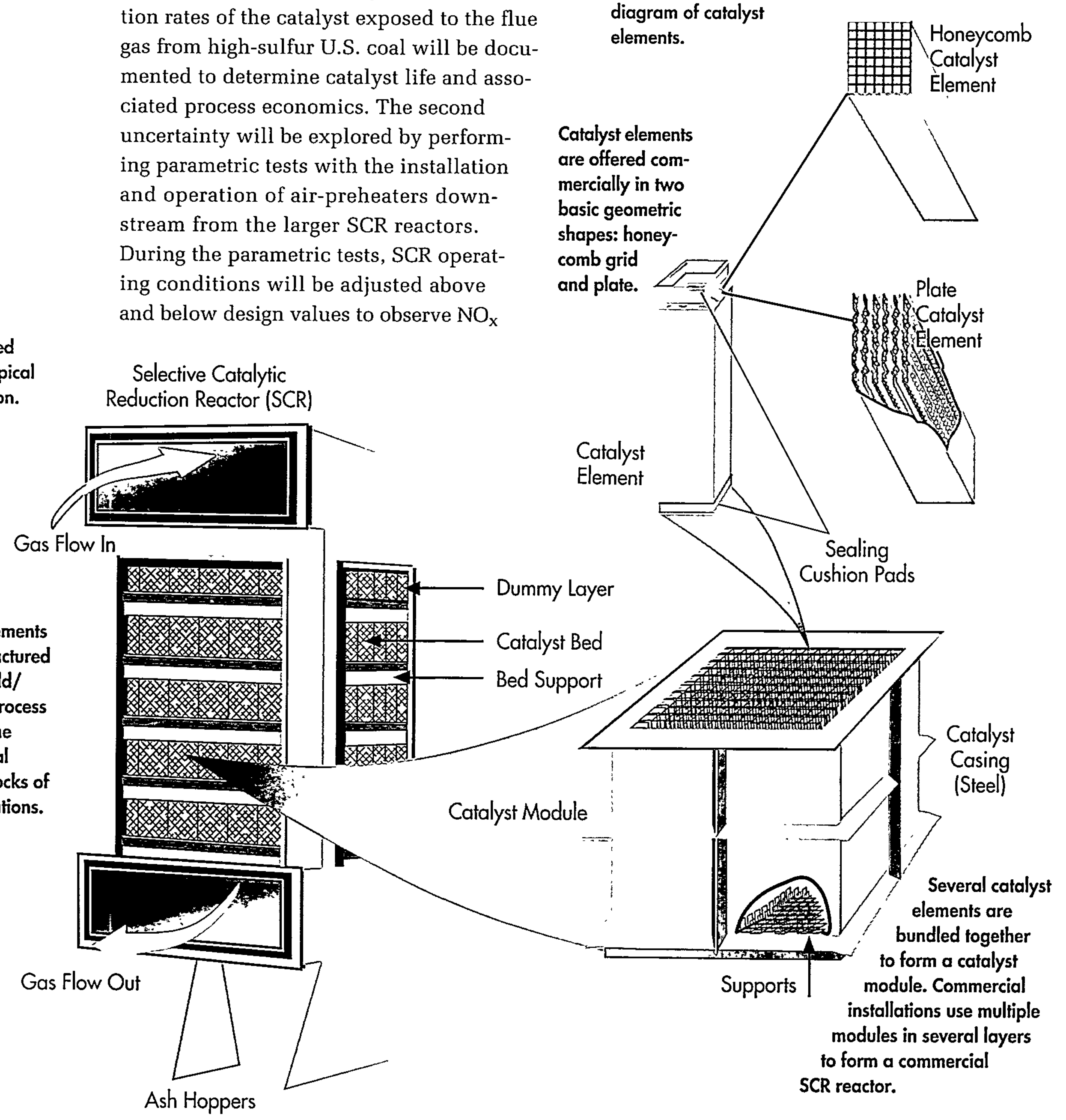


Figure 3. Detailed diagram of catalyst elements.

Catalyst elements are offered commercially in two basic geometric shapes: honeycomb grid and plate.

Figure 2. Detailed diagram of a typical SCR configuration.

Catalyst elements are manufactured using a mold/extrusion process and form the fundamental building blocks of SCR installations.

Several catalyst elements are bundled together to form a catalyst module. Commercial installations use multiple modules in several layers to form a commercial SCR reactor.

Advantages of SCR

Despite its potential problems, SCR remains the most technically advanced post-combustion technology available that is capable of reducing NO_x to the extremely low values mandated in certain areas of the world. Compared with other post-combustion NO_x-reduction processes, SCR is clearly the most mature process, having been used extensively worldwide on gas-, oil-, and low-sulfur-coal-fired utility power plants. Also, it has been applied at process scales up to 800 MW, whereas many of the other non-SCR processes have been tested only at laboratory scale. In this comparison, other SCR advantages that become apparent include the following:

- No chemical by-products that require marketing or off-gases that require regeneration or disposal are produced (only nitrogen and water vapor are formed).
- No significant re-engineering of the boiler heat exchange cycle is required.
- No solid adsorbents, with the concomitant high-energy consumption of handling and transfer, are required.
- Relatively little capital and operating costs are incurred.
- Simple chemical reactions improve the overall reliability of the plant.

Moreover, if the process can be properly designed for high-sulfur coal (to accommodate potential process chemistry problems), SCR will be inherently simple. Relative to other NO_x-reduction technologies, SCR is a dry process with few moving parts. Only the following boiler alterations are required:

- The ammonia metering system used to pump and vaporize liquid NH_3, dilute NH_3 with air, and inject the mixture in a ratio consistent with the NO_x concentration in the flue gas
- Modifications to the flue gas handling system
- Periodic soot blowing of SCR catalyst and air-preheater

Based on a comparison of other post-combustion NO_x-control technology, SCR emerged as the clear choice for demonstration by DOE's CCT Program. Altogether, PETC is managing 17 Clean Coal Technology (CCT) projects concerned with NO_x-reduction technologies that will help industry comply with EPA regulations.

Commercial Catalyst Performance with U.S. High-Sulfur Coal

Nine commercially available SCR catalysts are being evaluated at Gulf Power Company's Crist Unit 5 (75 MWe) to determine proper operating conditions and catalyst life for the SCR process. Co-sponsors of this CCT demonstration project are DOE; Southern Company Services, Inc., on behalf of the entire Southern Company; the Electric Power Research Institute (EPRI); and Ontario Hydro.

Crist Unit 5, located near Pensacola, Florida, is a tangentially fired, dry-bottom boiler with a hot- and cold-side electrostatic precipitator that uses high-sulfur coal (about 3% sulfur). Three U.S. suppliers (Englehard, Grace, and Cormetech), two European suppliers (Haldor Topsoe A/S and Siemens AG), and two Japanese suppliers (Hitachi Zosen and Nippon Shokubai Co., Ltd.) have been chosen to supply SCR catalysts that represent various shapes and chemical compositions.

The results from testing these catalysts will enable the evaluation of process chemistry and operation economics of applying SCR technology to flue gas, with high and low dust loadings, derived from the combustion of high-sulfur U.S. coal. The design engineering and construction have been completed. A 2-year long-term performance test began in July 1993. Qualitative results from tests performed on six of the nine reactors are available at this time. Table 1 gives the performance of the catalysts. The information is presented in terms of the catalyst's ability to meet the design criteria. In all cases, the tested catalysts either meet or exceed the design requirements. The goal of the demonstration is to show that SCR can achieve about 80% reduction of NO_x emissions from utility boilers firing high-sulfur U.S. coals (see Tables 1 and 2).

Table 1
Catalyst Performance

Catalyst	Number of Beds	Catalyst Type	NO_x Reduction	NH_3 Slip	SO_2 Oxidation	Change in Pressure
#1	3	HC	M	E	E	E
#2	3	HC	M	E	E	E
#3	2	PT	M	E	NA	E
#4	3	HC	M	E	E	E
#5	3	PT	M	E	E	E
#6	3	HC	M	E	E	E

M = Meets criteria
E = Exceeds criteria (i.e., performs better than required)
NA = Data not available for design case

HC = Honeycomb-type catalyst
PT = Plate-type catalyst
(The ammonia slip criterion is based on the catalyst's current slip values and is not a prediciton of slip after a 2-year life.)

SCR Reduction Demonstrated in the SNOX Process

The SNOX process is a flue gas cleanup technology that catalytically removes 95% of the SO_2, 90% of the NO_x, and over 99% of the particulate emissions (see *PETC Review,* Issue 6, "Low-NO_x Combustion Retrofit Projects"). The SNOX process is being demonstrated at Ohio Edison's Niles Station Boiler No. 2, a coal-fired cyclone boiler that typically burns 2 to 3% sulfur coal. The NO_x-reduction catalyst in this demonstration is the Haldor Topsoe DNX monolithic catalyst. SO_2 is removed as 93% sulfuric acid, following oxidation to SO_3 in a catalytic oxidative reaction downstream from the NO_x-reduction reactor. Co-sponsors of this CCT project are DOE, the Ohio Coal Development Office, ABB/ES, Snamprogetti, and Ohio Edison.

SNOX system operation on flue gas began in March 1992 and continued until December 1993. To date, test results confirm that the design removal efficiencies of 95% SO_2 and 90+% NO_x were met or exceeded, achieving 96% SO_x and 94% NO_x removal efficiencies.

This demonstration has shown that the methodology of the SNOX process offers a significant advantage over other SCR technologies using NH_3 that must operate with NH_3/NO_x molar ratios of less than 1.0 to limit the NH_3 slip past the SCR to 5 ppm or less. The constraint—to avoid ammonium salt scaling—limits the NO_x-removal efficiency of these processes to less than 90%. Any NH_3 slip in the SNOX process, however, is oxidized to NO_2 as it contacts the SO_2 converter catalyst downstream. This allows stoichiometric ratios of 1.00 to 1.05 and consequently higher NO_x-removal efficiencies without the adverse downstream effects of higher ammonia concentrations.

NO_x-Reduction Capabilities of SCR with SNRB

The SO_x-NO_x-Rox Box (SNRB) process is a combined, high-efficiency, multiple-emissions control technology for utility and industrial boiler applications developed by Babcock & Wilcox. SNRB incorporates dry sorbent

Table 2
Catalyst Design Criteria

Parameter	Value
Reactor Inlet NO_x	300–400 ppm
Particulate Loading	6–8 g/Nm^3
Maximum Pressure Drop (sum across catalyst beds)	1 kPa
Minimum Sustained Operating Temperature	620° F (327° C)
Maximum Sustained Operating Temperature	750° F (400° C)
Maximum Ammonia Slip at 2-Year Life (at design conditions)	5 ppm
NO_x Reduction Efficiency (while meeting above slip criteria)	80%
Maximum Number of Catalyst Beds	4
Maximum SO_2 Oxidation Rate (at design conditions)	0.75%

injection of sodium- or calcium-based absorbent for SO_x removal and SCR for NO_x reduction with a high-temperature pulse-jet baghouse for controlling particulate emissions (see *PETC Review,* Issue 6, "Low-NO_x Combustion Retrofit Projects"). The SNRB performance is being demonstrated at Ohio Edison's R.E. Burger Plant near Shadyside, Ohio, under sponsorship by DOE, the Ohio Coal Development Office, and EPRI. The system, which operated from mid-May 1992 through January 1993, accumulated approximately 1,700 hours of high-temperature operation. SO_2 emissions of 5.4 lbs/10^6 Btu (2.3 kg/GJ) from burning medium- to high-sulfur (3 to 4%) bituminous coal were reduced by 85 to 90%. Outlet SO_x emissions as low as 0.1 lb/10^6 Btu (43 g/GJ) were also achieved. Uncontrolled NO_x emissions of 0.85 lb/10^6 Btu (370 g/GJ) were reduced by more than 90% to as low as 0.03 lb/10^6 Btu (13 g/GJ) with less than 5 ppm ammonia slip. Particulate emissions from the industrial pulse-jet baghouse have consistently been less than 0.03 lb/10^6 Btu (13 g/GJ). The catalyst installed in each bag assembly was a zeolite-based Norton NC-300TM from Norton Chemical Process Products.

Figure 4 presents a cut-away view of a SNRB pulse-jet baghouse. The unique SNRB baghouse/catalyst configuration and operating temperature of 800 to 850°F (427 to 454°C) (conventional baghouses typically operate at 200 to 400°F [93 to 204°C]) provide for high NO_x-removal efficiencies by eliminating the need for reheating the flue gas to 550 to 750°F (290 to 400°C), which is typical of existing SCR installations.

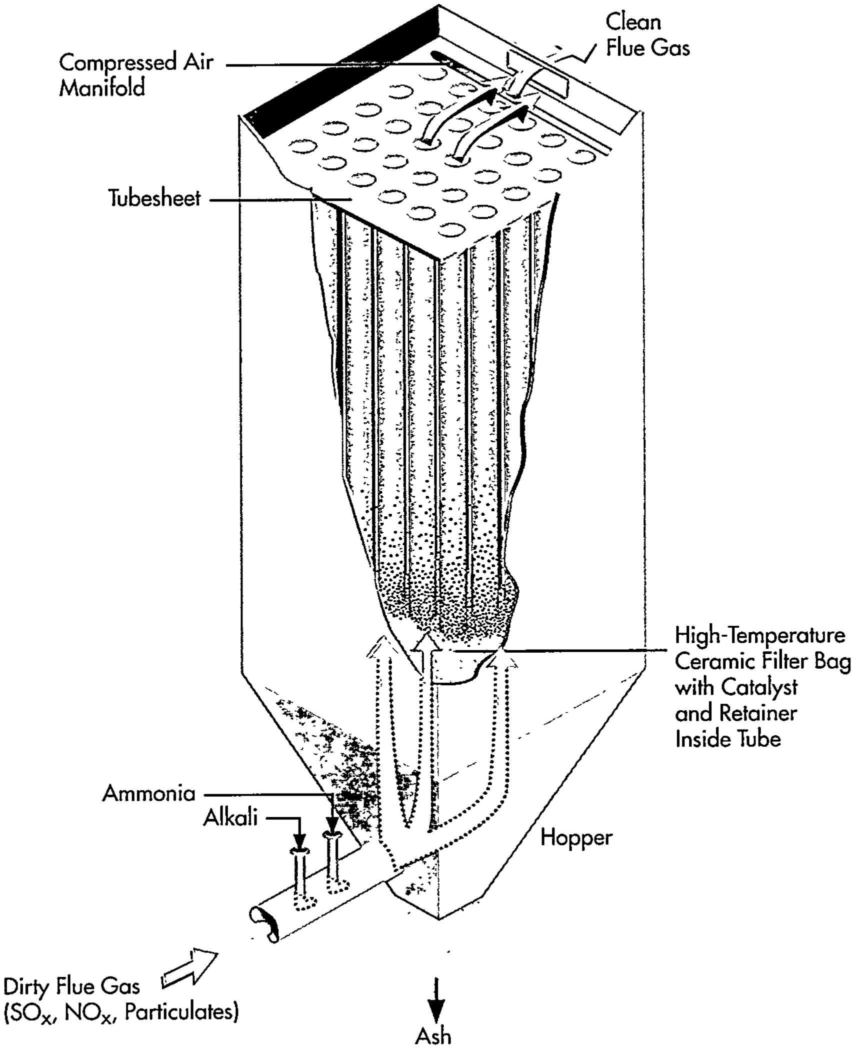
The SCR catalyst operating environment is also enhanced by the removal of particulates, SO_2, and SO_3 upstream of the catalyst. SNRB uses a high-temperature catalyst that is integrated into the baghouse in such a manner that the particulate loading and SO_x concentration are significantly reduced before the gas contacts the catalyst. This "clean" side integration of the catalyst promotes improved catalyst life by minimizing the potential for pluggage, erosion, and absorption of heavy metals from the fly ash. Thus, the potential for oxidation of SO_2 in the flue gas to SO_3 is also reduced.

The Selective Noncatalytic Reduction Process

In SNCR, urea is injected into a boiler flue where it reacts with the NO_x and oxygen in the flue gases to form nitrogen, carbon dioxide, and water without a catalytic converter. A urea-injection system is capable of removing 40 to 50% of the remaining NO_x from the combustion process.

Urea is much easier to handle and store than either aqueous ammonia or anhydrous ammonia used in SCR. Although SNCR is simpler and costs less than the competing SCR system, it removes less NO_x (40 to 50% compared with about 80% for SCR) and has the potential for higher ammonia slips. The SNCR process must operate within a specific boiler temperature range, about 1700 to 1900°F (925 to 1,040°C).

Figure 4. Cut-away diagram of an SNRB pulse-jet baghouse.



If the temperature is too high, some of the urea can actually be converted to NO_x. If the temperature is too low, some of the urea is converted to ammonia, creating an unacceptable new pollutant. Urea injection technology is not new. Research sponsored by EPRI (current holder of the SNCR patent) from 1976 to 1981 established that urea was effective for NO_x removal.

Full-Scale Demonstration of SNCR

SNCR is being demonstrated in conjunction with several control technologies at the Public Service Company of Colorado (PSCC) Arapahoe Steam Electric Generating Station located in southwest Denver, Colorado. Co-sponsored by DOE, PSCC, and EPRI, the Arapahoe 4 Project is integrating a dry NO_x/SO_2 emissions control system consisting of five major control technologies that combine to form an integrated system for controlling both NO_x and SO_2 emissions: (1) low-NO_x burners, (2) overfire air, and (3) SNCR to control NO_x emissions; (4) dry sorbent injection using either sodium- or calcium-based reagents to control SO_2 emissions; and (5) a humidification system.

Arapahoe 4 is a 100-MWe roof-fired unit placed in service in 1955. Only 65 roof-fired units similar to Arapahoe are installed in the United States. Roof-fired units are characterized by a small furnace with a very turbulent flame. NO_x emissions are very high compared with wall- and tangentially fired boilers and are in the range of 1.15 lbs/10^6 Btu (0.5 kg/GJ). The Arapahoe unit's main fuel is a low-sulfur (0.4%) Western bituminous coal, but moderately high-sulfur (2.5%) Illinois coal is also being used in the demonstration. The goal of SNCR at Arapahoe is to provide up to an additional 40% NO_x reduction from the reduced levels already obtained with combustion modification.

Noell, Inc., was selected to design and supply the urea-based SNCR system at Arapahoe. Figure 5 shows a simplified flow diagram of the system as implemented at Arapahoe. Urea is received in a 65% aqueous urea solution and stored in one of two 20,000-gallon (76 kL) storage tanks. Because the concentrated urea solution will crystallize at about 115°F (46°C), the solution is continually circulated through an electric heater system. A small slipstream of the urea is filtered, mixed with recycled softened water to further dilute the urea, and pumped at high pressure (300 to 600 psig [2.0 to 4.7 MPa]) to Noell's proprietary injection nozzles. A centrifugal compressor is used to supply a large volume of medium-pressure (6 to 12 psig [41 to 82 kPa]) air at the injection nozzles to help atomize the urea solution and rapidly mix the urea with the flue gas.

The SNCR system at Arapahoe has two injector levels. The lower (or hotter) level injects urea countercurrent to the flue gas at about a 45° angle downward. The upper-level injectors are located immediately above a row of screen tubes and below the primary superheater. Each of the levels has ten injectors placed 3.5 feet (1.1 m) apart.

Initial baseline testing of the urea injection system began in February 1992 and will continue until mid-1994. The system is performing well, and total NO_x-reduction levels of about 30% have been obtained at full load with minimal ammonia slip. At lower loads, the temperatures cool so that only 10% removal can be obtained with low ammonia slips. Emissions monitoring of nitrogen dioxide (NO_2), conducted continuously during the test program, indicates that urea converted 10% of the NO_x to N_2.

Demonstration of NO_xOUT

SNCR NO_xOUT technology will be demonstrated on the New York State Electric and Gas (NYSE&G) Milliken Station Unit 2 near Lansing, New York. The NO_xOUT process will be provided by Nalco Fuel Tech. Other sponsors of the upcoming demonstration are DOE, NYSE&G, and EPRI.

The NO_xOUT process is a new chemical and mechanical system for cost-effective NO_x reduction from fossil-fueled and waste-fueled combustion sources. The NO_xOUT process uses patented chemical enhancers and mechanical modifications to widen the temperature range (between 1,600 and 2,100°F [870 and 1,150°C]) over which the urea solution will react with the NO_x to form nitrogen, carbon dioxide, and water. SO_2 will be removed by a chemically enhanced wet-limestone scrubber.

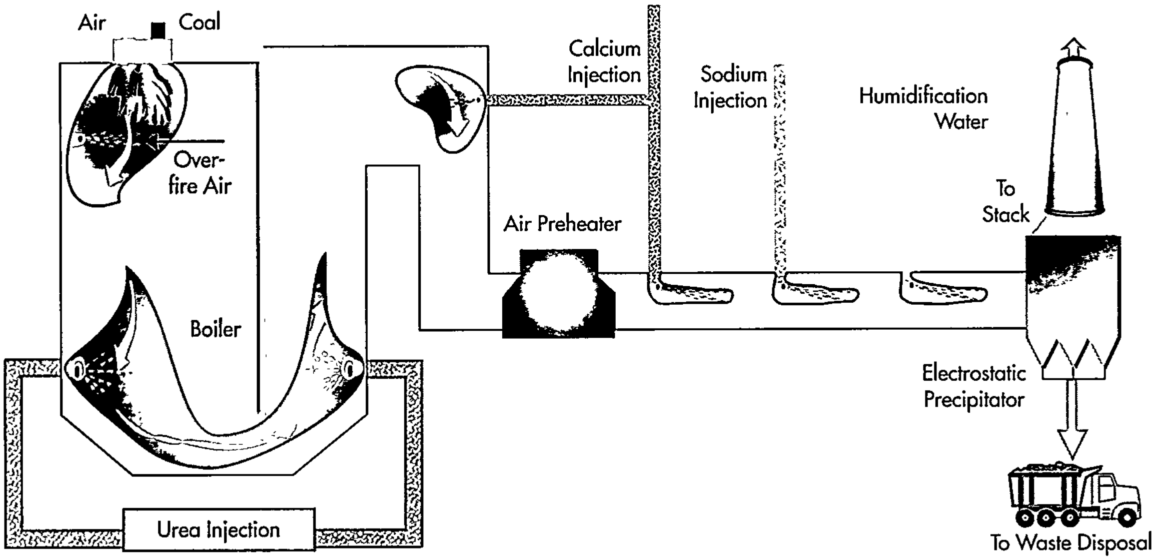


Figure 5. Flow diagram of the urea-based SNCR system at Arapahoe Steam Electric Generating Station in Denver.

The Milliken demonstration project, currently in its design phase, would be the first application of the NO_xOUT enhanced urea injection SNCR on a high-sulfur, coal-fired boiler. The design was completed in 1993, and construction is scheduled for completion in 1994. Operational testing will start in 1995.

The innovative technology envelope representing the SNCR system would include the NO_xOUT solution injection equipment and the process configuration of the injection nozzles for high-sulfur, pulverized-coal systems. Based on pilot-scale and oil-fired full-scale testing, a 30 to 50% incremental reduction in NO_x emissions is projected.

With regard to uncontrolled NO_x emissions, NYSE&G's Milliken Station currently emits about 6,900 tons (6,264 tonnes) per year. The proposed demonstration project would reduce NO_x emissions to 4,700 tons (4,267 tonnes) per year or less by improving station efficiency and modifying the combustion process through the installation of advanced overfire air, low-NO_x burners, and windboxes. NO_x would be further reduced by at least 20% through the inclusion of the NO_xOUT SNCR systems.

A Strategic Remedy

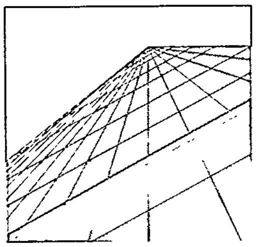
Utilities must rely on retrofit technology to successfully remove both NO_x and SO_2 from existing coal-burning utility plants, while not increasing production of any other of the 189 substances they are required to monitor. DOE's goal is to remove at least 99% of SO_2 and 95% of NO_x produced from the combustion of coal. SCR/SNCR are relatively simple and low-cost post-combustion retrofit technologies that will play a vital role in the utilities' compliance strategies. By investigating all aspects of retrofit technologies, such as SCR and SNCR, PETC's CCT demonstrations provide valuable data, information, and operating experience to the EPA in accomplishing its environmental mission.

CALENDAR

September 6–8, 1994	**Third Annual Clean Coal Technology Conference** Location: Chicago, Illinois Contact: Joseph Strakey — (412) 892–6124
September 6–8, 1994	**Liquefaction Contractors Review Meeting** Location: Pittsburgh, Pennsylvania Contact: Gilbert McGurl — (412) 892–4462
September 12–16, 1994	**11th Annual International Pittsburgh Coal Conference** Location: Pittsburgh, Pennsylvania Contact: Bruce Utz — (412) 892–5706
*** September 29, 1994**	**Regional Technology Transfer Meeting for High-Efficiency SO_2 Removal** Location: Pittsburgh, Pennsylvania Contact: Janice Murphy — (412) 892–4512
October 6–7, 1994	**Sixth Triple E Seminar (Enrichment seminar for elementary level instructors)** Location: Pittsburgh Energy Technology Center Contact: McMahan Gray — (412) 892–4826
October 8, 1994	**Fall Granular Flow Advanced Research Objective (GFARO) Review and Planning Meeting** Location: Philadelphia, Pennsylvania Contact: Sean Plasynski — (412) 892–4867
1994	**Symposium on the Transfer and Utilization of Particulate Control Technology** Location: Washington, DC Contact: Charles Drummond — (412) 892–4889
1994	**International Conference on Managing Hazardous Air Pollutants: State-of-the-Art** Location: Washington, DC Contact: Charles Drummond — (412) 892–4889
1994	**EPRI/EPA/DOE 1994 SO_2 Control Symposium** Co-sponsors: Electric Power Research Institute Environmental Protection Agency Location: TBD Contact: Charles Drummond — (412) 892–4889

*** Tentative**

HIGHLIGHTS



Outgrowth and evolution of PETC research.

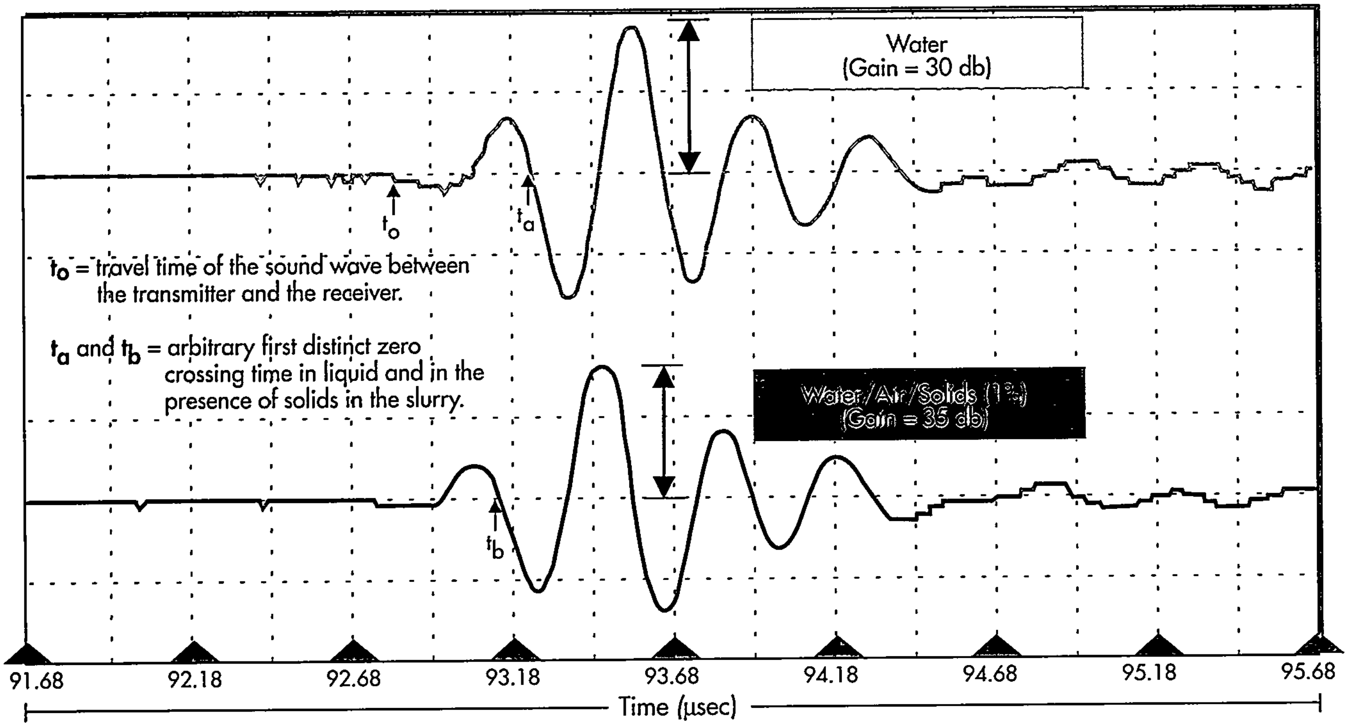
Solids Concentration Measurement in a Three-Phase Reactor—Ultrasonic Technique

Application of the three-phase slurry reactor system for indirect coal liquefaction processing by the Fischer-Tropsch process has recently received considerable attention. To design and efficiently operate a three-phase slurry reactor, the degree of dispersion of the solid (catalyst) in the reactor must be understood. The most obvious methods of making this measurement, such as optical and direct sampling, are adversely affected by perturbation of the reaction system or by difficulty in obtaining measurements because of high pressure, temperature, or opacity of the slurry phase. A novel method involves the measurement of ultrasound transmission developed at the Pittsburgh Energy Technology Center (PETC) using a technique for the direct measurement of solid concentrations in a three-phase slurry reactor.

Because the velocity of sound in a liquid differs significantly from that in a solid, a time shift and an amplitude change in the sound wave relative to those parameters for the pure liquid can be detected when solid particles are present in a slurry. Theoretically, the solids concentration can be correlated to the relative time shift. In a slurry reactor, the solids concentration can be measured by sending an ultrasonic pulse across the slurry and measuring the amplitude and time shift of that portion of the transmitted pulse received at the opposite side of the reactor. Clearly, the presence of the solids caused a substantial decrease in both the amplitude of the sound wave and in the transit time as shown in the figure below. Typical data of the ultrasonic signal is affected by 1 wt% of solids. Here, t_a and t_b are the arbitrary first distinct zero crossing time in liquid and in the presence of solid in the slurry. The travel time of the sound wave between the transmitter and the receiver is defined as t_o.

The preliminary study of the ultrasonic technique conducted in the water/air/glass bead system has demonstrated the feasibility of this technique under ambient conditions in a three-phase reactor. Current efforts are underway to apply the ultrasonic technique under temperature and pressure with molten wax as the liquid phase.

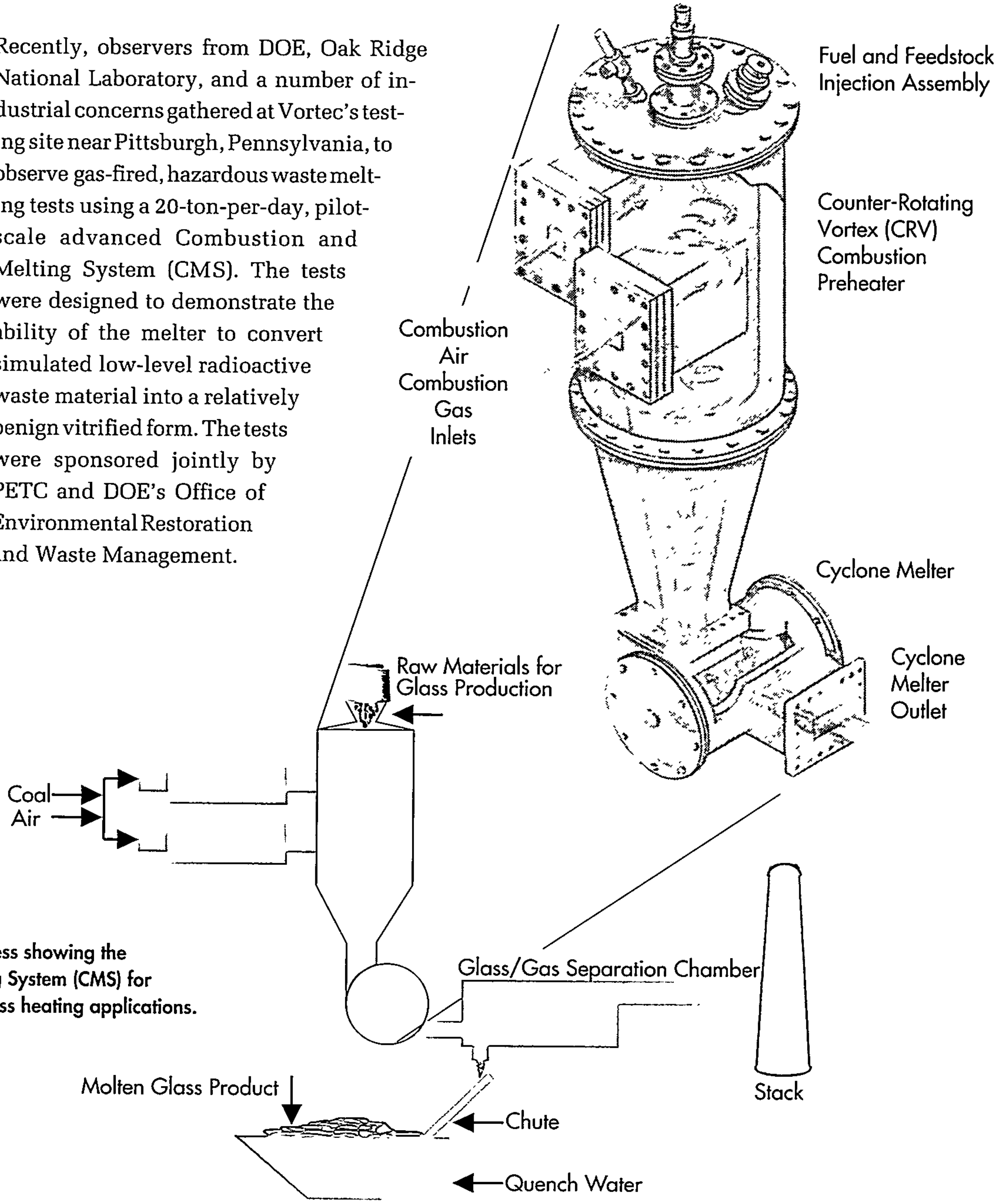
Typical data of an ultrasonic signal as affected by 1 wt% of solids.



Vitrification Tests of Surrogate Low-Level Radioactive Incinerator Ash Successfully Conducted

More than 100,000 tons of hazardous low-level radioactive waste material are now being stored at various sites around the country in drums or simply left in place as large tracts of contaminated soils. Drum storage is a very costly yet temporary solution. Impoundment is equally unattractive because the contaminated material may be released into the environment. Disposal of these materials in secured landfills is not permitted because of the potential for leaching of contaminants into the groundwater. In the past, no single disposal method has shown the ability to effectively destroy toxic organic contaminants and vitrify the inorganic portion of the waste to prevent leaching during long-term storage. Now it appears that a coal-fired industrial melting process developed with Department of Energy (DOE) funding may provide a near-term solution to this pressing disposal problem.

Recently, observers from DOE, Oak Ridge National Laboratory, and a number of industrial concerns gathered at Vortec's testing site near Pittsburgh, Pennsylvania, to observe gas-fired, hazardous waste melting tests using a 20-ton-per-day, pilot-scale advanced Combustion and Melting System (CMS). The tests were designed to demonstrate the ability of the melter to convert simulated low-level radioactive waste material into a relatively benign vitrified form. The tests were sponsored jointly by PETC and DOE's Office of Environmental Restoration and Waste Management.



Vortec vitrification process showing the Combustion and Melting System (CMS) for selected industrial process heating applications.

The basic function of the CMS is to rapidly heat glass-forming materials to high temperatures that are well above the melting point of the mixture. Heat is supplied by the combustion of relatively small quantities of coal or other fossil fuels introduced at the top of the counter-rotating vortex (CRV) combustor which efficiently transfers heat to the glass-forming material in a highly turbulent flow field. Physical and chemical reactions are completed in a cyclone melter positioned below the CRV. The CMS not only melts most inorganics but also destroys any organic material that might be present. Any inorganic material contained in the feed, such as ash or contaminated soil, is uniformly dispersed throughout the molten glass and subsequently becomes permanently immobilized upon solidification. After melting is completed, the mass flows from the cyclone melter to an enclosed reservoir where gases are separated from the molten material. In the case of glass manufacturing, the glass can then be transported to the appropriate finishing process. The gaseous combustion products pass through a waste-heat recovery unit and are then quenched with water and passed to a wet electrostatic precipitator to remove particulates.

The Vortec project is one of three currently active efforts sponsored by PETC that are designed to stimulate the use of coal by the industrial sector in an efficient and environmentally compatible manner. The phased development of the coal-capable Vortec advanced melting system was initiated by PETC in 1986. The CMS is now in the third and final phase of refinement. Phase I consisted of an initial feasibility assessment. In Phase II, the basic CMS system was constructed and preliminary lab- and pilot-scale testing were conducted. Tests conducted under Phase II showed that the melter can be fired with pulverized coal and/or natural gas to produce glass cullet from waste glass. These same tests revealed that the process would be able to comply with the most stringent U.S. emissions standards for glass-melting operations without the additional need for SO_x and NO_x control equipment. Preliminary technical and economic analyses showed that the CMS had the potential to increase the energy efficiency of the glass melting process by 25% (versus conventional glass-melting technology) while decreasing capital costs by a similar percentage. The ongoing Phase III of the Vortec CMS project is intended to generate the CMS operating data required for commercialization of this advanced melting technology.

In Phase III, an integrated pilot-scale glass manufacturing facility was assembled. More than 500 hours of actual testing (glass production) will be performed in this 3-year project phase. This testing will include several short-duration exploratory tests and 100-hour proof-of-concept tests. At this stage of development, the CMS has already proven itself in a number of high-temperature melting, smelting, and waste recycling and vitrification applications. CMS applications include the production of usable glass and mineral fiber products from a variety of conventional and non-conventional sources. Feedstocks have included coal ash from an industrial boiler, sewage sludge ash, waste container glass, and glass and fiber process wastes. Ash vitrification tests have shown that the CMS product is non-leachable, leading to Vortec's participation in programs concerning soil remediation sponsored by the Environmental Protection Agency (EPA) and DOE's Morgantown Energy Technology Center (METC). Recognizing the near-term commercial potential of the CMS system, several private-sector industries (including a major U.S. supplier of insulation fiber products and a major equipment supplier for the mineral fiber industry) have begun to provide significant support for the development effort.

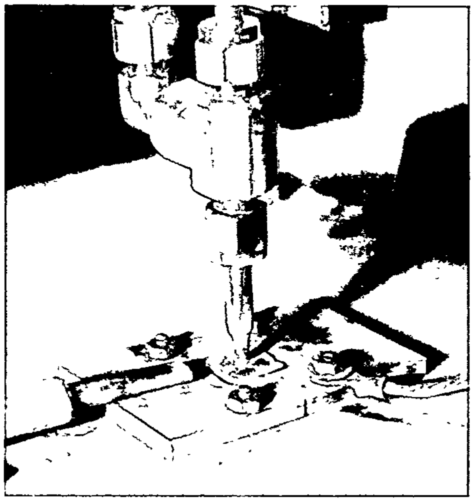
CRADA with Montec Associates, Inc.

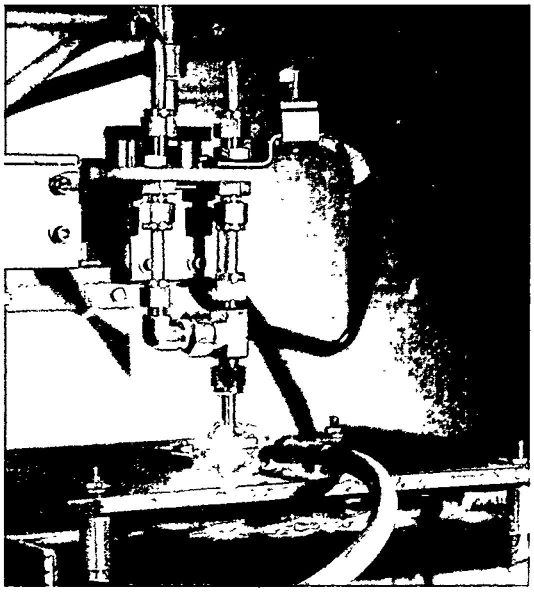
A Cooperative Research and Development Agreement (CRADA) between the Pittsburgh Energy Technology Center (PETC) and Montec Associates, Inc., has been initiated. The objective of this effort is to develop electrode materials for various arc-mode devices by capitalizing on and extending the readily available information obtained from magnetohydrodynamics generator studies.

This information is applicable to plasma arc electrodes that are used in metals processing and also have applications in the field of hazardous waste destruction and vitrification. The project was initiated by fabricating electrodes using various materials, including platinum-tungsten-capped elements and various tungsten and tungsten-based materials, both wrought and press-sintered, some of which were doped with various materials to enhance high-temperature strength and increase oxidation resistance. A bench-scale test apparatus has been designed and constructed to provide a systematic evaluation of arc-mode electrode configurations and materials wear mechanisms.

The atmosphere in the arc region was varied with air and argon as cover gases, and some tests included the use of an oxygen-acetylene flame to simulate the background heat flux. Experiments have been conducted on anodes identical to those tested in a prototypical magnetohydrodynamics generator under load conditions. These tests indicated that the bench-scale test process is suitably designed to provide a method to screen electrode material designs for operation in an arc-mode regime. Parametric investigations of electrode wear, as a function of arc strength and arc dwell time, were completed to determine the effect of arc heating on wear.

Preliminary results show that the wear is dominated by arc strength and that a threshold arc level of 12 amps or greater will result in catastrophic wear of platinum caps and high wear rates for the tungsten caps. These electrodes are currently being characterized by PETC using various state-of-the-art analytical surface characterization techniques, including scanning electron microscopy, energy dispersive spectroscopy, and X-ray photoelectron spectroscopy, to determine wear and damage mechanisms for the electrodes.





A bench-scale test unit showing design and construction. This will provide a systematic evaluation of arc-mode electrode configurations and materials-wear mechanisms. (Test rig set up by Busek Company, Needham, Massachusetts.)

3rd Annual Regional Science Bowl Pushes Correct Buttons for Participants and Volunteers

On Saturday, February 12, 1994, participants from 32 high schools in the southwestern section of Pennsylvania came to the Community College of Allegheny County (CCAC) to compete in the 3rd Annual Regional Science Bowl, co-sponsored by PETC, CCAC, and others.

PETC, CCAC, and the other co-sponsors supplied the volunteers who served as time keepers, rules judges, score keepers, technical judges, and moderators for each round of the competition. The final rounds of the competition were held in PETC's Conference Center on Wednesday, February 16, 1994.

The winner of the southwestern regional, Gateway High School, went on to compete in the National Science Bowl in Washington, DC where they placed seventh overall.

- Above—The Southwestern Pennsylvania Regional Science Bowl winners of Gateway High School. From left to right: Pat Gerity, CCAC–South Campus liaison; Gateway High team members, James Kiger, Ian Tzeng, Innate Mak, Albert Hwang, Matthew Perlman, and coach, Donald Vosnick; Kay Downey, Science Bowl Coordinator, PETC.

- Above—Students from Canevin Catholic High School confer during a break in the action. From left to right: Brandon Jacoby, Melissa Connelly, Kathleen Davis, and Anthony Roscoe.

- Above—CCAC provided the facilities and the lunch for Science Bowl participants and volunteers.

- Left—Volunteer Coordinator, Jacqueline Balzarini of PETC (left) and Lucille Katz of Gilbert/Commonwealth, verify scores at the end of a round of competition.

RD&D AWARDS

Research, Development, and Demonstration (RD&D) Awards are awarded by PETC as (1) grants to universities, (2) contracts to corporations, or (3) clean coal cooperative agreements with industry. They support key scientific and engineering projects identified by PETC as vital to the nation's energy interest. For reports resulting from these contracts, please contact either:

(1) For DOE employees and its contractors:
Office of Scientific & Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576–8401

(2) The general public:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487–4650

Please note—there are fees connected with these services.

Date of Award	Awardee	Project/Contract Number
Coal Combustion		
9/1/93	University of Kentucky Mechanical Engineering Department Lexington-Fayette, Kentucky	Radiation-Turbulence Interactions in Pulverized-Coal Flames FG22-93PC93210
9/30/93	Brigham Young University Mechanical Engineering Department Provo, Utah	Investigation of Mineral Transformation and Ash Deposition During Staged Combustion FG22-93PC93226
10/1/93	University of Oklahoma Norman, Oklahoma	Combustion of Pulverized Coal in Vortex Structures FG22-93PC93221
Coal Preparation		
8/26/93	University of Alabama Chemistry Department Tuscaloosa, Alabama	Molecular Accessibility in Oxidized and Dried Coals FG22-93PC93202
9/1/93	Colorado State University Fort Collins, Colorado	Temperature Effects on Chemical Structure and Motion in Coal FG22-93PC93206
9/1/93	Iowa State University Mining and Minerals Research Ames, Iowa	Development of a Gas-Promoted Oil Agglomeration Process FG22-93PC93209
9/1/93	Pennsylvania State University University Park, Pennsylvania	Surface Properties of Photo-Oxidized Bituminous Coals FG22-93PC93223
9/1/93	University of Michigan Ann Arbor, Michigan	Biological Determinants of Photobioreactor Design FG22-93PC93212
9/1/93	University of Nevada Reno, Nevada	Novel Microorganism for Selective Separation of Coal from Ash and Pyrite FG22-93PC93215

9/1/93	University of South Carolina Columbia, South Carolina	Large-Scale Coal Solubilization and Bioconversion to Utilizable Energy FG22-93PC93224
9/9/93	University of Cincinnati Cincinnati, Ohio	Production of Sulfur and Methane from H_2S and CO_2 from a Coal Desulfurization Process FG22-93PC93220
9/15/93	Western Kentucky University Bowling Green, Kentucky	Multiparameter On-Line Coal Bulk Analysis FG22-93PC93211
9/20/93	University of Arkansas Electronics & Instrumentation Department Little Rock, Arkansas	Electrostatic Beneficiation of Coal FG22-93PC93203
9/30/93	Tecogen, Inc. Waltham, Massachusetts	Integration of Thickener Underflow into Thermal Dryer Circuit AC22-93PC93156
11/1/93	Energy International, Inc. Pittsburgh, Pennsylvania	Improvement of Storage, Handling, and Transportability of Fine Coal AC22-93PC93157

Coal Utilization

9/3/93	National Academy of Sciences Energy Engineering Board Washington, DC	Strategic Assessment of the U.S. DOE's Coal Program FG22-93PC93035
9/8/93	Alberta Research Council Edmonton, Alberta Canada	Seventh International Conference on Coal Science FG22-93PC93626
9/23/93	Duke University Durham, North Carolina	Novel Carbon Ion Fuel Cells FG22-93PC93219

Environmental Control Technology

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9/1/93	Lehigh University Chemistry Department Bethlehem, Pennsylvania	NO Decomposition in Non-Reducing Atmospheres FG22-93PC93222
9/1/93	Michigan Technological University Metallurgical Engineering Department Houghton, Michigan	Separation of Flue-Gas Scrubber Sludge into Marketable Products FG22-93PC93214
9/2/93	University of California Berkeley, California	Analysis of Microalgae Ponds for Conversion of CO_2 to Biomass FG22-93PC93204
9/24/93	Advanced Tech Systems Monroeville, Pennsylvania	Evaluation and Further Development of Various Sampling and Analytical Methods for Determining Specific Toxic Emission from Coal-Fired Power Plants AC22-93PC92583

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9/1/93	North Carolina A&T State University Chemical Engineering Department Greensboro, North Carolina	Preparation and Characterization of Composite Membrane for High-Temperature Gas Separation FG22-93MT93008
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Sid Friedman, Senior Technical Editor of the *PETC Review*, was a major contributor to several feature articles this issue. Sid authored the insightful article, *What Is Coal?*, and contributed to two pieces on PETC's international activities, *PETC's Overseas Activities* and *Build It and They Will Come.* In addition to his duties with the *Review*, Sid is a Senior Technical Advisor in the Office of Research and Development and serves as Publication Quality Assurance Officer for PETC. Sid joined the Coal Research Center of the U.S. Bureau of Mines, the predecessor of PETC, 39 years ago and has performed and directed research in a variety of areas related to coal and synthetic fuel chemistry.

Mildred B. Perry supplied material for *Build It and They Will Come.* As Research and Development Group Leader in the Flue Gas Cleanup Division, Mille has had the opportunity to work directly with some of the foreign researchers who have come to PETC. Also contributing to this article was **Robert C. Dolence,** a Program Coordinator in the Office of Project Management, also oversees Systems and Engineering Analysis.

As International Program Coordinator, **Susan D. Laczko** provided important background information for the *Overseas Activities* article. Susan has been actively involved in PETC's international activities for 20 years. Since 1990, she has been assisting the DOE Office of Export Assistance in promoting energy exporting initiatives in Eastern Europe and the former Soviet Union. **Douglas F. Gyorke** provided images and information for the portion of the article dealing with PETC's work in Poland. Doug, a Project Manager in the Coal Utilization Division, oversees the Krakow project. Material for the section on Thailand was supplied by **Richard E. Tischer.** Dick is a Project Manager in the Liquid Fuels Division in the Office of Project Management. **William C. Peters** furnished information regarding PETC's work with India. Bill, as a Project Coordinator in the Advanced Power Generation and Fundamental Research Division, works with developing nations in resolving power generation needs. Additional input was provided by International and Public Affairs Coordinator, John W. Hindman.

Herbert L. Retkofsky was the primary contributor to the article, *The 7th International Conference on Coal Science.* Herb spent nearly his entire professional career with PETC, working his way from laboratory technician to Deputy Associate Director for Research and Development. In addition to his work as a scientist, throughout his career, Herb has been very active in science education activities.

NO_x Reduction by SCR/SNCR was written with material and data supplied by **Arthur L. Baldwin** and **Ronald W. Corbett.** Art is Program Coordinator for NO_x Control Technologies in PETC's Office of Clean Coal Technology, and Ron is a Project Manager in Clean Coal, where he oversees the work on a number of projects.

FROM THE EDITORS

Changing of the Guard

It is said that the only thing constant is change, and so it goes with the *PETC Review*. Once again the *Review* announces a change in personnel with the retirement of Richard R. Santore, Editor-in-Chief. Dick came on board the *Review* during production of Issue 5, assisting then Editor-in-Chief, Dr. Bernard D. Blaustein. He succeeded Dr. Blaustein in that position for Issue 6, with Bernie staying on through Issue 7 as a Senior Technical Editor to assist with the transition. Dick continued serving as Editor-in-Chief through Issue 9. In addition to his duties with the *Review,* Dick remained the Deputy Associate Director of the Office of Clean Coal Technology at PETC, a position he held for 4 years. Since coming to DOE in 1975, Dick has managed a variety of projects for PETC in the Liquid Fuels Division and served as assistant operations manager at the Synthane coal gasification pilot plant. He also served a stint as on-site operations manager at DOE's H-Coal Liquefaction Pilot Plant. Dick plans to enjoy retirement with his wife, Marilyn, pursuing his passion for tennis and golf, and spending time with his five children and their families. We wish him well.

While we bid Dick Santore farewell, the *PETC Review* welcomes Dr. Kee H. Rhee as the new Editor-in-Chief. In addition to his position with the *Review,* Kee has also been named Senior Scientist for the Office of Research and Development (RD). Before his appointments, Kee was a Senior Technical Advisor in the Coal Preparation Division of RD and was assigned stewardship of the Center's Science Outreach Program. Kee developed and implemented highly successful programs as head of the Outreach Program, including the Triple E Seminar, and the Elementary Teacher Research Internship (ETRI) program, both for teachers at the elementary level. He was also instrumental in establishing the Scientist/Engineer Resource Volunteers for Education (SERVE) program. The SERVE program involves PETC professionals volunteering as consultants and advisors to teachers and students, as well as classroom lecturers/demonstrators for grades K through 12.

Kee has kept in contact with both former Editors-in-Chief, Dick and Bernie, drawing on their experience with the *Review* to help guide him through his initial issue. Kee has also relied on the expertise of Senior Technical Editor, Dr. Sid Friedman, who has served in this capacity since Issue 7. Sid brings a wealth of knowledge to the *Review* with his 39 years of experience at the Center performing and supervising coal and synthetic fuels research. Another anchor of support during this transition has been Jamey Reiss, Managing Editor. She has served in this capacity since the *Review's* inception and provides a ready reference to past efforts. Kee has added additional support by naming three contributing technical editors to the *Review* staff: Michael L. Eastman, PETC's Quality Improvement Advocate; Dennis H. Finseth, a Research Chemist and Group Leader in the Coal Preparation Division of RD; and Lawrence A. Ruth, Coal Utilization Division Director.

And so the guard has changed, but the mission remains the same—Kee Rhee will now lead the efforts of the *PETC Review* staff to share PETC's knowledge of cost-effective and environmentally acceptable power generation and to promote clean coal technologies worldwide.