Electricity in Industry

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Cover: The speed and intensity of the melting process in an electric arc furnace is several times greater than in a combustion furnace.

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Industry's Move to Electricity

Electric plasma arc torches at 10,000°F are reducing low-grade ores to iron in a single step. Microwaves are drying fabrics in the textile industry more uniformly and completely with less expenditure of energy. Ultraviolet lights are being used to cure polymeric paints in seconds, where minutes of heating have been required in the past. Computer-controlled robots are using lasers to weld automobile body seams faster and more precisely than previously possible. These examples illustrate how electricity, used efficiently in improved or in entirely new ways, promises to make future industrial operations more energy-efficient, cleaner, and—the key—more productive.

These and other processes take advantage of the unique characteristics of electric energy: precise control, which allows energy to be applied efficiently where and when it is needed; ease of conversion to whatever energy form is most suited to do a job; and high thermodynamic potential, which makes it possible to achieve uniquely high power levels and temperatures.

Driven by the prospect of high energy productivity, the move to electricity is already occurring in some sectors of U.S. industry. For example, General Motors Corp. plans to have 14,000 robots in operation on assembly lines by 1990; a 50% increase in electric steel making is expected by the late 1980s; and electric induction furnace growth is estimated at between 500 and 1000 MW per year nationwide. This move will affect U.S. utilities, not only in the possible need for more kilowatthours but also through impacts on load curves and power quality. It will be important for the utility industry to become more deeply involved in these developments so that their effects can be understood and guided to the mutual benefit of utility and customer. This involvement must begin at the R&D stage if utility planning and guidance are to be truly effective; it thus becomes an area for EPRI involvement also.

In Europe, where prices of electricity and other forms of energy traditionally have been high, the importance of energy efficiency and productivity has been recognized for some time, and electric utility research organizations have worked closely with the industrial sector to develop productive new uses for electricity. Joint projects and closely coordinated R&D are being carried out in Germany, England, France, and other countries on such processes as electromelting, mechanical vapor recompression and other industrial heat pump applications, microwave drying, and membrane concentration.

In response to utility industry needs and encouragement, and stimulated by some of the European models for cooperation, EPRI is now assessing the potential of a series of electrification technologies and the opportunities for their development in close cooperation with major energy-using industries. Planning workshops have been held with key individuals and institutions in the steel, metals fabrication, chemical, and textile industries; workshops with several other industries are planned for later this year. Specific plans for cooperative R&D projects are now emerging from this interaction and from parallel technical assessments conducted over the last year in EPRI's Industrial Applications Program. This program's goals over the next few years will be to catalyze the development of R&D centers for electricity-based technologies and develop cost-shared demonstrations with industry on electrification technologies. Achievement of these goals not only will promote industrial application and adoption of new electricity-based processes but will also help the utility industry plan for changes that such adoption might bring.

Robert Mauro, Manager
Industrial Applications Program
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Authors and Articles

Industry has been especially successful at energy conservation, its efforts contributing significantly to the general slowing of growth in U.S. electricity consumption. However, conservation is not always as simple as just cutting demand. This month's lead article, **Electrotechnology: Sparking Productivity in Industry** (page 6), points out several technology innovations that make for better industrial productivity and cost-effectiveness—better conservation in the long run—through increased use of electricity. Science writer Mary Wayne describes examples from the work of Philip Schmidt, a consultant to the research program managed by Robert Mauro of EPRI's Energy Utilization and Conservation Technology Department.

Mauro, who has been with EPRI since 1978, took charge of research in industrial energy conservation technologies in January 1981. He was formerly director of research for the American Public Power Association. Mauro is a physics graduate of Loyola College in Baltimore, Maryland.

Philip Schmidt, a professor of mechanical engineering at the University of Texas (Austin), has consulted with EPRI since 1978, most recently spending his sabbatical year on a full-time study of industrial electrification. Schmidt has been on the Texas engineering faculty since 1970, and he was associate dean of the graduate school between 1978 and 1981. He has held consulting and advisory posts in industry and in state and federal government since 1973, specializing in energy conservation technologies, systems, and programs. Schmidt graduated from MIT in aeronautics and astronautics; he earned MS and PhD degrees in mechanical engineering at Stanford University.

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Improving the thermal efficiency of coal-fired power plants by 1% would not do a thing for Pacific Gas and Electric Co. It would be worth millions in the American Electric Power Co., Inc., system. It's a matter of which utilities burn coal. EPRI does not try to compare R&D payoffs that specifically, but **The Value of 1%** (page 16) reviews how the Institute is using regional comparisons to gain useful precision in R&D planning. John Douglas, science writer, wrote the article, aided by James Mulvaney of EPRI's Planning and Evaluation Division.

Mulvaney, a senior planning engineer, has been on the EPRI staff since September 1978, evaluating the potential benefits of R&D avenues. He was previously a planning engineer for the generation, transmission, and distribution systems of Long Island Lighting Co. for 9 years. Mulvaney has a BSEE from Clarkson College of Technology and an MS from the State University of New York at Stony Brook.

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Poor fuel quality at a power plant soon shows up as poor thermal efficiency and, beyond that, as a lengthening record of plant repairs and lost availability for service. The problem is to know what solution will be cost-effective, and when. For many coal-burning utilities, the answer is coal cleaning and the time is now; they will be the first to benefit from the range of research and testing reviewed in **Cleaner Coal for Power Plants** (page 24). The article was written by Jenny Hopkinson, *Journal* feature writer, aided by two research managers from EPRI's Coal Combustion Systems Division.

Frederick Karlson has managed the Coal Quality Program since he came to the Institute from Bechtel Civil & Minerals, Inc., in January 1981. He was with Bechtel for 16 years, the last 5 as a project engineer in the Mining and Metals Division. Karlson's work there included a study for DOE of connections and distinctions between coal mining and coal conversion technologies. His earlier assignments involved design and site engineering on large pilot facilities for flue gas desulfurization processes. Karlson graduated in chemical engineering from Lafayette College (Pennsylvania), and he studied combustion technology at Imperial College (London).

Douglas Trerice is manager of EPRI's Coal Cleaning Test Facility. Since joining the Institute in July 1979, he has been responsible for design and construction of the facility, design of the research and test program, startup, and operation. Trerice was formerly with Kaiser Engineers, Inc., for five years, successively as a resident engineer and project manager for coal mine development and coal preparation plant design. He earlier worked for seven years in the design, construction, and operation of aluminum and other metals production facilities.

Trerice has a BS in chemical engineering from Queen's University in Ontario (Canada).

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Electric power R&D is usually seen in small pieces, whether by researchers themselves, their advisers and consultants, or utility managers. Each individual or group sees only one facet most of the time, and it takes purposeful effort even to look for others. **Trends in Electric Power Technologies** (page 30) presents an R&D mosaic that is big enough for the pattern to emerge. The article is based on a speech given by Chauncey Starr, EPRI's first president and now a vice chairman, at the 1981 Engineering Educators Banquet of the Edison Electric Institute. It has been adapted for the *Journal* by Nadine Lihach, senior feature writer.

In his day-to-day role since May 1978, Starr heads EPRI's Energy Study Center, conducting and guiding studies to correlate energy use—especially electricity—with other societal and economic factors. Before January 1973, when he began to organize EPRI, Starr was for 6 years dean of the School of Engineering and Applied Science at the University of California at Los Angeles. He had previously been with Rockwell International Corp. for 20 years, 6 of those years as president of the Atomics International Division.

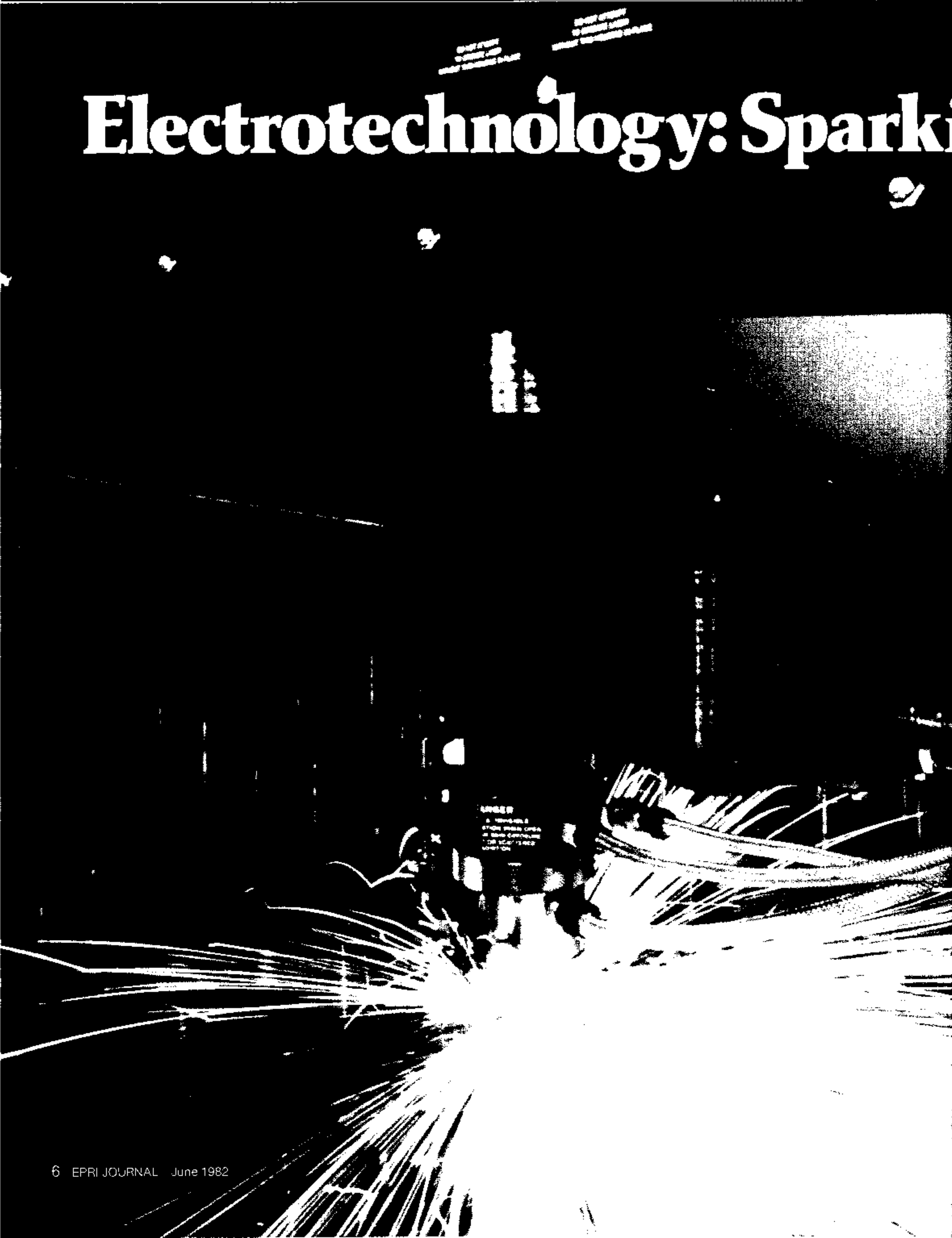
Trerice Karlson

Mulvaney

Mauro Schmidt

Starr

Electrotechnology: Sparki



g Productivity in Industry

Electricity is more than just another interchangeable energy form; it affords entirely new technologies with finer process control, higher conversion efficiencies, and greater potential for automation than many conventional manufacturing processes. Basic industries are now taking advantage of these energy attributes in their efforts to boost productivity.

Photo courtesy Coherent Inc.

Production costs in U.S. industry have risen steeply in recent years, fueling domestic inflation and dulling the competitive edge of American goods on world markets. The problem is well known. The question is what can be done, given the seemingly intractable costs associated with land, labor, capital, energy, raw materials, and environmental protection.

One response now gaining attention is the effort to develop and commercialize new technologies that can avoid many of the expenses linked with conventional industrial processes. Innovative technologies that rely on electricity rather than direct combustion of fossil fuels look especially promising.

But how can industry save money by switching to processes that use a form of energy that is more, not less, expensive? Electricity now costs industrial customers about $15 per million Btu, whereas oil costs $8 and gas about $4. The answer to this paradox—and the reason why electrification of U.S. industry could help restore the nation's industrial might—begins with the unique properties of electric energy.

Electricity is unique

Electricity is the most highly organized form of energy. It is virtually 100% convertible into useful work, whether that work be moving a rotor, melting a metal, or pulling apart molecules to effect a chemical change. In contrast, whenever any other form of energy is converted into work, some of the energy is lost. A familiar example is the heat lost to the atmosphere when the thermal energy released by fuel combustion is applied to an industrial task.

The highly organized character of electricity has several important implications. First, because little of the electric energy is wasted, its work efficiency is greater, and less of it is needed to get the job done.

Just as important, the organized nature of electric energy makes it easy to control with a precision unmatched in conventional thermal processes. The energy can be applied to a workpiece at carefully chosen points, for precise periods of time, and in precise amounts. Electricity can even generate heat inside an object, an industrially valuable feature known as volumetric energy deposition.

Inherent physical constraints limit the temperatures that can be achieved by burning fuels, but there are no such limits with electricity. Industrial combustion typically provides temperatures up to 3000°F (1650°C), and even the purest hydrogen fuels yield temperatures no higher than about 5000°F (2760°C). By comparison, electric heating processes can easily achieve temperatures around 10,000°F (5540°C) and higher.

Conventional fuel-based industrial equipment is usually geared to the use of one fuel and no other. The costly equipment conversions and reconversions of recent years testify to the drawbacks of such inflexibility. Electric process equipment, in contrast, can run on power generated from a great variety of fuels. It involves none of the fuel transportation and handling problems that can plague fuel-based operations. And it is compatible with a wide range of processes and existing equipment.

Finally, electricity is clean at the point of use. Besides preventing fume or residue damage to the materials being processed, electricity use relieves industry of much of the responsibility and cost associated with health and safety and environmental regulations. Controlling the impacts of fuel combustion takes place back at the power plant.

So electricity has unique advantages for the industrial user. All energy forms are not equal when it comes to efficiency, controllability, intensity, flexibility, and environmental desirability. A Btu of heat energy produced by electricity, though more expensive than a Btu produced by oil, gas, or coal, may be the most economical choice as a process base when all the requirements of a manufacturing process are taken into account.

Electricity-based technologies

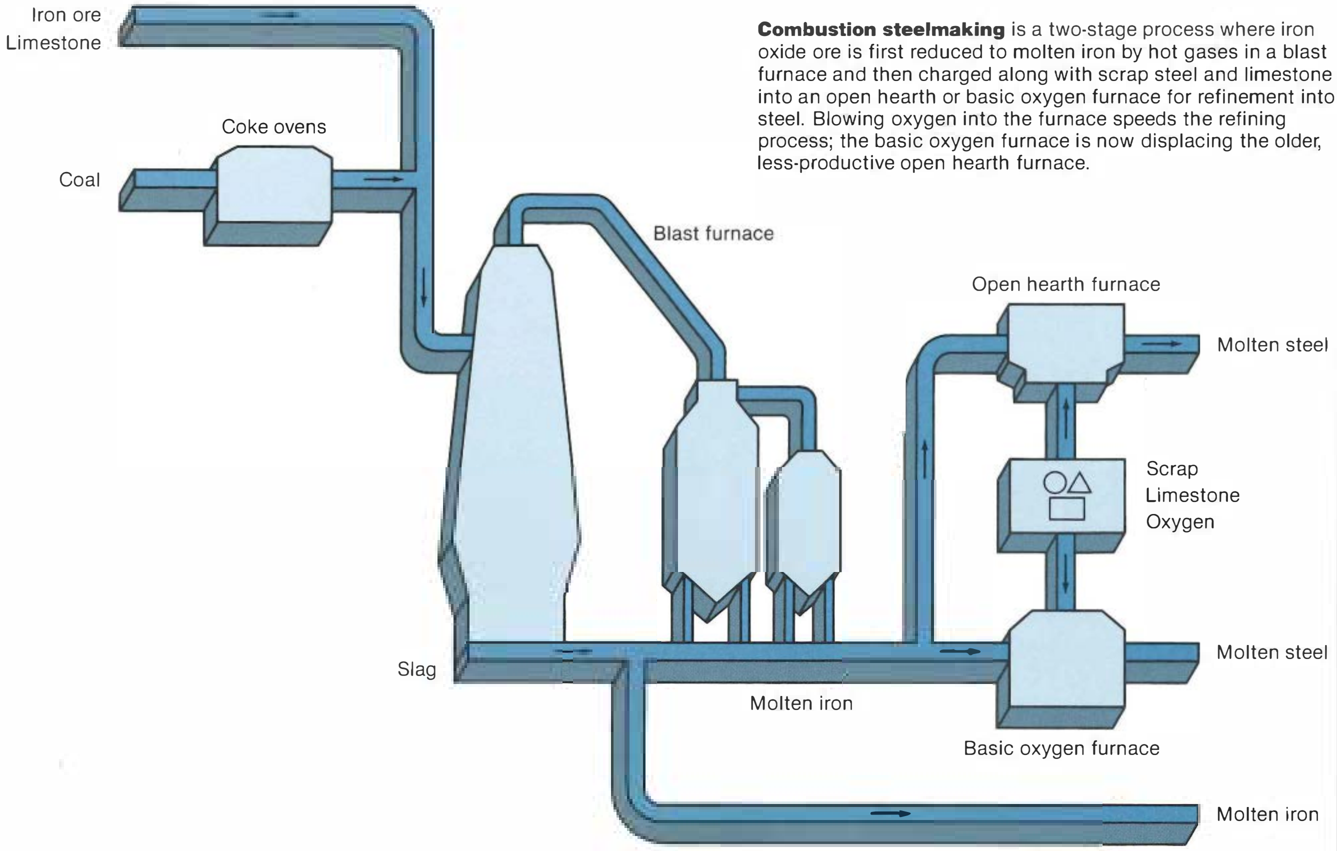
Electrification potential is greatest in those industries that are already among the nation's leading energy consumers: steel and other metals, automobiles, chemicals, petroleum, glass, paper, food, and textiles.

Many applications would substitute electric energy for combustion-based process heat, but the applications are not limited to heating. Philip S. Schmidt, who is conducting industrial electrification studies with EPRI's Energy Management and Utilization Division while on leave from the University of Texas, divides applications into four major categories: high-temperature materials production, high-temperature materials fabrication, medium- and low-temperature materials production, and coating and finishing uses. Looking at some examples from Schmidt's own work reveals the wide range of opportunities being opened up by various electricity-based technologies.

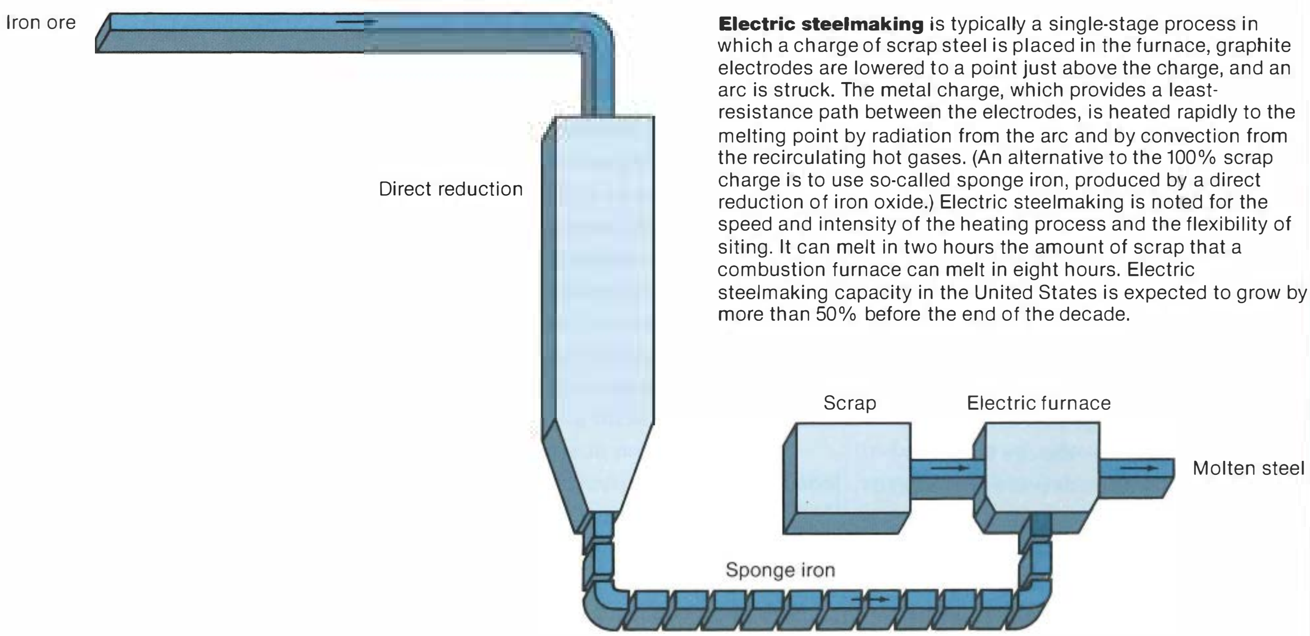
Prime in the high-temperature materials production category is the use of electric arc furnaces to melt metals, especially steel scrap. The speed and intensity of the heating process in an electric arc furnace allow steelmakers to recycle the nation's inventory of scrap, which combustion furnaces are not hot enough to handle effectively. It would take a combustion furnace eight hours or more to melt the same amount of scrap that an electric furnace can melt in two hours or less. This shortcut to the production of fresh molten steel eliminates many of the costly steps that must be executed in integrated steel operations, which begin with iron ore.

Called minimills because of their size, electric steelmaking operations take up little land and can be conveniently sited close to scrap sources and steel markets. The American Iron and Steel Institute predicts a growth of over 50% in electric steelmaking capacity in the United

COMPARISON OF COMBUSTION AND ELECTRIC STEELMAKING



Combustion steelmaking is a two-stage process where iron oxide ore is first reduced to molten iron by hot gases in a blast furnace and then charged along with scrap steel and limestone into an open hearth or basic oxygen furnace for refinement into steel. Blowing oxygen into the furnace speeds the refining process; the basic oxygen furnace is now displacing the older, less-productive open hearth furnace.



Electric steelmaking is typically a single-stage process in which a charge of scrap steel is placed in the furnace, graphite electrodes are lowered to a point just above the charge, and an arc is struck. The metal charge, which provides a least-resistance path between the electrodes, is heated rapidly to the melting point by radiation from the arc and by convection from the recirculating hot gases. (An alternative to the 100% scrap charge is to use so-called sponge iron, produced by a direct reduction of iron oxide.) Electric steelmaking is noted for the speed and intensity of the heating process and the flexibility of siting. It can melt in two hours the amount of scrap that a combustion furnace can melt in eight hours. Electric steelmaking capacity in the United States is expected to grow by more than 50% before the end of the decade.

To cure the coating on the outside of beverage cans, industry has traditionally baked the cans in gas-fired ovens for about eight minutes. A new electrical curing method focuses ultraviolet waves on a special light-sensitive film applied to the can's surface, curing the coating in about one second. In addition to being a cleaner and faster process, this method cuts costs for space, maintenance, equipment, and energy.

States by 1988, most of it resulting from replacement of conventional combustion-driven facilities. But what will happen when the supply of steel scrap available for recycling is exhausted?

Fortunately, as Schmidt points out, the electric arc furnace is not only efficient but versatile. It can easily adapt to a diet of direct-reduced iron, known as sponge iron, as either a supplement to scrap or a substitute for it. Moreover, SKF Steel of Sweden already has a commercial plant in operation that can electrically produce 70,000 tons of sponge iron a year. The SKF method exposes the ore to electrically generated plasmas (very hot ionized gases), triggering a rapid chemical reaction that separates the iron from the ore's waste products.

The action of any plasma process depends on the fact that large amounts of energy are absorbed by the gas to dissociate and ionize its atoms, energy that is rapidly given up to a cooler surface upon contact. Very high rates of heat transfer can occur in the same way that heat is transferred when steam condenses. Plasmas can be generated by electric arcs and then used in a variety of ways—not just to effect chemical reactions, as in ore reduction or the commercial synthesis of chemical compounds (another promising area), but also to rapidly cut or melt metals and other tough materials.

Induction heating, lasers, and flywheels

High-temperature processes for fabricating metals into useful items offer additional opportunities to apply new electric technologies. One of the fastest-growing applications is the use of induction heating to soften metal billets before forging. As the name suggests, heat is actually induced within the billet rather than being transferred to it by direct contact with a heated substance. The method is to place the conductive billet in a rapidly fluctuating magnetic field, which induces electric currents in the billet itself, resulting in rapid heating.

Induction heating is typically used for forming steel, aluminum, magnesium, and titanium parts, such as the rods that connect the pistons to the crankshaft in an automobile engine. In 1981 U.S. industry's installed capacity for such induction heating applications (exclusive of melting) was in the range of 5000–10,000 MW, enough to consume the full annual output of 5 to 10 large power plants. The expected annual growth of these applications is 10–15%, or 500–1000 MW. Thus induction heating is an established and growing technology based on the volumetric energy deposition possible only with electricity.

Lasers are a more recent arrival in the array of electrically based technologies. A solid or a gas (typically carbon dioxide for industrial uses) is stimulated electrically to produce a high-intensity beam of coherent, well-collimated light. This beam can then be focused and manipulated by means of mirrors or lenses to deposit its energy at just the spot desired on the surface of the target material. A laser beam's energy density—the amount of energy that can be concentrated in one square inch of surface—can be one million times as great as that of an oxyacetylene torch, the laser's conventional combustion counterpart.

Besides being more powerful than a combustion torch, a laser beam works with far greater precision. For example, such a beam can be used to drill the thin passageway inside a hypodermic needle. At high intensities, the laser beam literally vaporizes the material it strikes. At lower intensities, it can heat-treat the surface of parts that experience heavy stress, hardening them at just the points where they would be most likely to wear out. Heat treatment of the crankshaft area where the piston rods connect is one of many applications for lasers in the automotive industry.

At present, about 65–70% of industrial lasers in the United States are concentrated in electronics production, where they are used to drill, cut, and scribe very small, delicate parts. Probably another 15% are used in the auto and aerospace industries, where their combination of power and precision meets a number of heavy manufacturing needs. Because lasers can be handled easily by computerized robots, their future applications in manufacturing appear virtually boundless. John Brushwood, a project manager in the Energy Management and Utilization Division, estimates that there are now some 4200–4600 materials-processing lasers in industrial use in this country.

In contrast to the laser, homopolar pulsed heating for high-temperature materials fabrication is not yet an industrial reality. This technique would rely on a familiar energy storage device, the flywheel. The idea is to bring a massive, electrically conducting flywheel up to a very high speed and then suddenly place it in a magnetic field, thus converting its store of kinetic energy into a sharp burst or pulse of electric current. By this method an enormous amount of stored energy could be converted and directed to a workpiece almost instantly. Schmidt estimates that a steel billet that would take several minutes to heat in an electric induction furnace (and several hours in a combustion furnace) could be heated by pulsed electricity in less than a second. The barrier is that this technology, under development for the past decade in pursuit of its potential for firing fusion reactors, is still too experimental and too expensive for industrial use.

In the category of high-temperature materials fabrication, then, the electric technologies discussed form a spectrum: from commercially proven induction heating to emerging laser applications to the exciting potential of homopolar pulsed heating.

Microwaves and soda cans

Medium- and low-temperature applications of electricity are closer to home. Many electrically based techniques for heating, cooling, and drying materials at less intense temperatures are already familiar to consumers in the form of microwave ovens, infrared lamps, and home heat pump systems ("Directing Heat Flow," *EPRI Journal,* May 1981, p. 6). Efforts to scale up these technologies for industrial use are in progress.

Microwave techniques for industrial heating and drying rely on the same principle as the home microwave oven. Certain compounds, notably water, are composed of molecules that snap to attention in the presence of an electric field, instantly aligning themselves in the direction of the current. If the field reverses, so do the molecules. This back-and-forth molecular motion within a water-containing substance generates heat that can cook it or dry it out through speedy evaporation.

Besides extensive use in the food-processing industry, microwave technology has potential in the textile and paper industries, where a substantial amount of energy goes toward removing the moisture from washed fabrics and wood pulp. Microwaves are already an important part of two other production processes: the heating and curing of rubber and rubber products and the curing of molds in the metal-casting industry.

An example of the finishing applications of electricity-based processes comes from the beverage industry. Curing the coating on a beer or soda can by the traditional method means heating the whole can. It is first covered with a coating in a volatile solvent base, then placed in a gas-fired oven to drive off the solvent and set the finish.

The electrical alternative focuses more narrowly on the can's surface. First the can is coated with a special light-sensitive film; then the surface is exposed to electromagnetic waves in the form of ultraviolet radiation. With this method the surface is cured in about one second, as opposed to the eight minutes typically required to heat the whole can to the curing point in a gas-fired oven. Moreover, the electric process offers a cleaner and more comfortable working environment, without the solvent vapors and heat that are emitted by gas-fired ovens.

This sampling of electrically based innovations gives only a taste of the many processes and applications that are possible. Some of these new process technologies are already beginning to revive the ailing industries that first nibbled and now show a healthy appetite for innovation. But some industries are more receptive than others. As Schmidt comments, "Different kinds of technical innovations penetrate the market in different ways and at different rates." What, then, is the market outlook for more widespread use of new electric technologies in U.S. industry?

Market constraints

Wholesale adoption of the new processes will not occur overnight. Certain features of industrial decision making will, in fact, work against them.

One is the huge investment in existing plant and equipment. Billions of dollars are tied up in hardware for conventional industrial production methods, and this hardware typically has a longer useful life than consumer items like cars or commercial equipment like typewriters and computers. The life of a combustion boiler, for example, is usually measured in decades.

Perhaps even more important in the case of industry, a technology on the verge of obsolescence often goes through an Indian summer of renewed vigor before it gives way to newer methods. The same economic pressures that stimulate innovation also stimulate improvements in the performance of existing processes. Since the mid-1970s, for example, industrial combustion equipment has become substantially more efficient through the addition of heat recovery systems, better controls, and improved burners. Such improvements mean that new processes are chasing moving targets.

Lead time is another barrier to new processes. Putting a new production method in place always brings delays, which can result in anything from lackluster performance to failure to deliver the product, a serious consequence in any business. Reorienting the company's personnel and procedures, especially when raw materials not previously used must be procured, takes even more time and poses more problems. Fear of these snags in the transitional phase often reinforces an industry's reluctance to try something new.

Waiting for someone else to make the first move slows things down even further. The well-established market structure within industries gives rise to what Schmidt calls the Why me? syndrome. As long as the competition does not disturb the existing price structure, it is easier for an industrial manager to maintain business as usual than to take the risk of introducing a new process that might adversely affect product quality if it does not operate properly.

Future demand uncertainties also constrain innovation in cyclical industries, such as steel and chemicals. Not knowing how much output will be required shortens the planning horizon for capital expansion.

Finally, industrial managers contemplating a change to electricity-based technology may observe pressures on the electric utilities and wonder how these will affect future electricity prices. Utilities are perceived as middlemen whose business costs are influenced not only by fuel suppliers but also by the money market, government regulators, environmentalists, and consumer groups. What will be the impact on an industry's energy costs if it commits itself to electricity-based processes? Some industries remain cautious, despite the likelihood that oil and gas prices will rise more rapidly than electricity prices.

Economics: impetus to electrification

Balancing these doubts and uncertainties are the very real and demonstrable economic advantages of many electric process technologies.

Time is money on the production line, and electric processes are often faster than their combustion counterparts because of the higher energy intensity possible with electricity. Packing more production into a smaller time span spreads all the costs of production over a larger volume of output, reducing the cost per unit. In the lumber industry, for example, a rapid microwave drying system for hardwoods has been estimated to cost only about $40 per thousand board feet dried, in contrast to $55 for the same amount in a conventional kiln. These figures include both capital and operating expenses. Drying time is reduced from 25 days to 1 day.

Equipment for electric processes can typically be made in smaller and less costly unit sizes than combustion equipment because fuel handling and environmental requirements are met at the power plant instead of the factory. The capital cost of the electrically based plasma iron-smelting process developed by SKF Steel in Sweden is $150 per ton per year, in contrast to $360 for the conventional coke-based blast furnace process. And the smaller electric units also take up less space, thus reducing that expense.

Electric processes can save energy, too, even taking into account the three-to-one conversion ratio of fuel to electricity at the power plant. Integrated steel mills use 23.5 million Btu to produce one ton of molten steel, for example, whereas electric minimills use only 7.4 million Btu per ton. Some might object that the minimill operation begins with scrap steel and so involves far fewer steps, but Schmidt considers the comparison valid, pointing out that what counts is getting the product out at the lowest total cost. Skipping steps that the conventional process must follow and using alternative raw materials are fine; in fact, these changes are the essence of the technological innovation that allows electric minimills to consistently outperform the integrated steelmakers. In 1979 it cost integrated mills an average of $447 to produce a ton of steel, whereas the scrap-based electric mills were able to do so for only $306, or about a third less, resulting in a profit per ton about two to three times higher.

The smaller-scale equipment and fewer process steps typical of electric technologies also tend to reduce labor requirements for both operation and maintenance. An induction furnace in a 30,000-t/yr steel-forging operation, for example, requires only one operator, while a gas-fired furnace typically requires two. And the combustion furnace needs twice as much maintenance. The resulting annual labor outlays for operation and maintenance are $60,000 for the electric unit and $120,000 for the gas unit.

Preventing materials loss during processing also holds down costs. For example, when a metal billet is heated externally by combustion heat, the surface can crack because of thermal stress and scale can form because of gradual oxidation. Electric induction heating offers the advantages of volumetric (internal) energy deposition as well as rapid, high-intensity processing, which reduces surface stress and gives scale little time to form.

A well-maintained gas furnace in a forging operation will still lose about 2% of its raw material throughput to scale, and another 1% of the heated product will have to be scrapped for failure to meet quality standards. But with electric heating, these losses can be cut to 0.5% and 0.25%, respectively. Switching to electricity can slash the annual bill for scale and scrappage loss in a 30,000-t/yr forging operation from $600,000 to about $150,000.

Harder to quantify but potentially even more important are the savings that can come from substituting low-cost domestic raw materials for scarce and/or high-cost imported materials in U.S. industrial production. This benefit goes well beyond substituting coal or uranium for high-cost industrial fuels, although that is one important aspect of the savings. For example, the critical high-grade ferrochrome and ferrovanadium ores used by U.S. manufacturers to make steel alloys for industrial and defense purposes now come mostly from African countries. With the new plasma processes for ore reduction, it may be feasible to use lower-grade American ores instead. The implications for both industrial economics and national security are substantial.

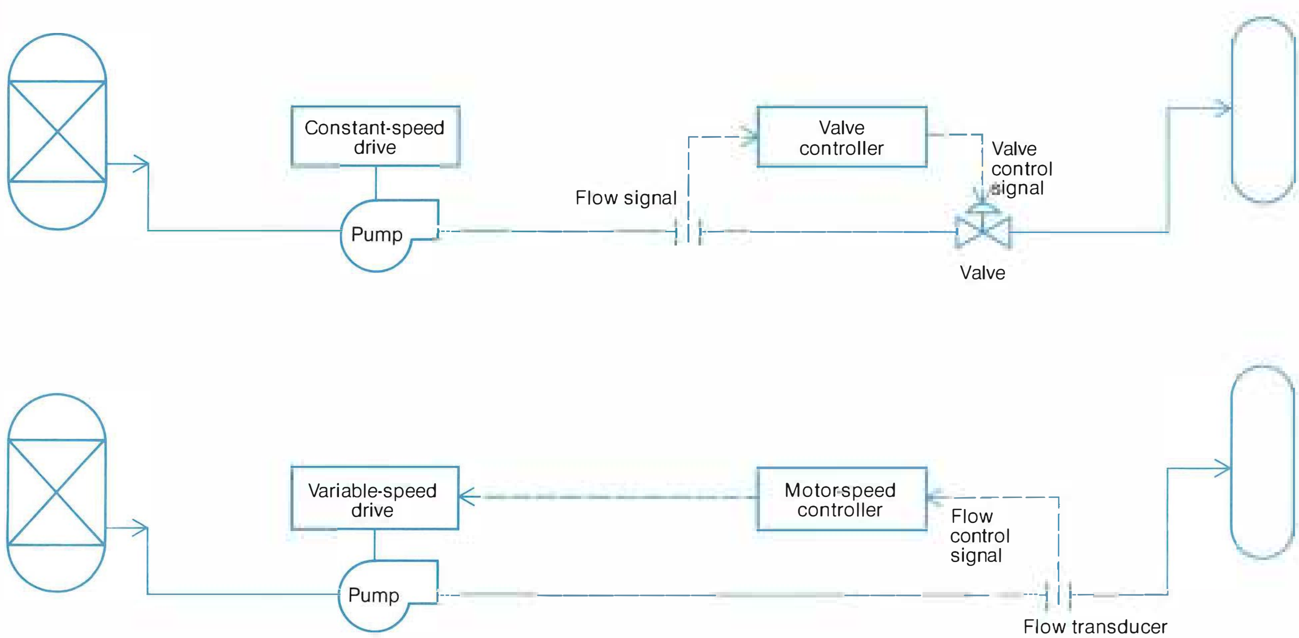
To wrap up this review of economic benefits, consider the case of the beverage cans. Rapid curing by the ultraviolet method is cheaper, despite the higher cost of the coating used, because of savings in other areas. The costs of ultraviolet curing now being used in a large brewery compare very favorably with the costs of a gas-fired system: the electric system incurs only 10% of the space, 25% of the maintenance, 40% of the energy, and 60% of the equipment costs that the gas-fired system must bear.

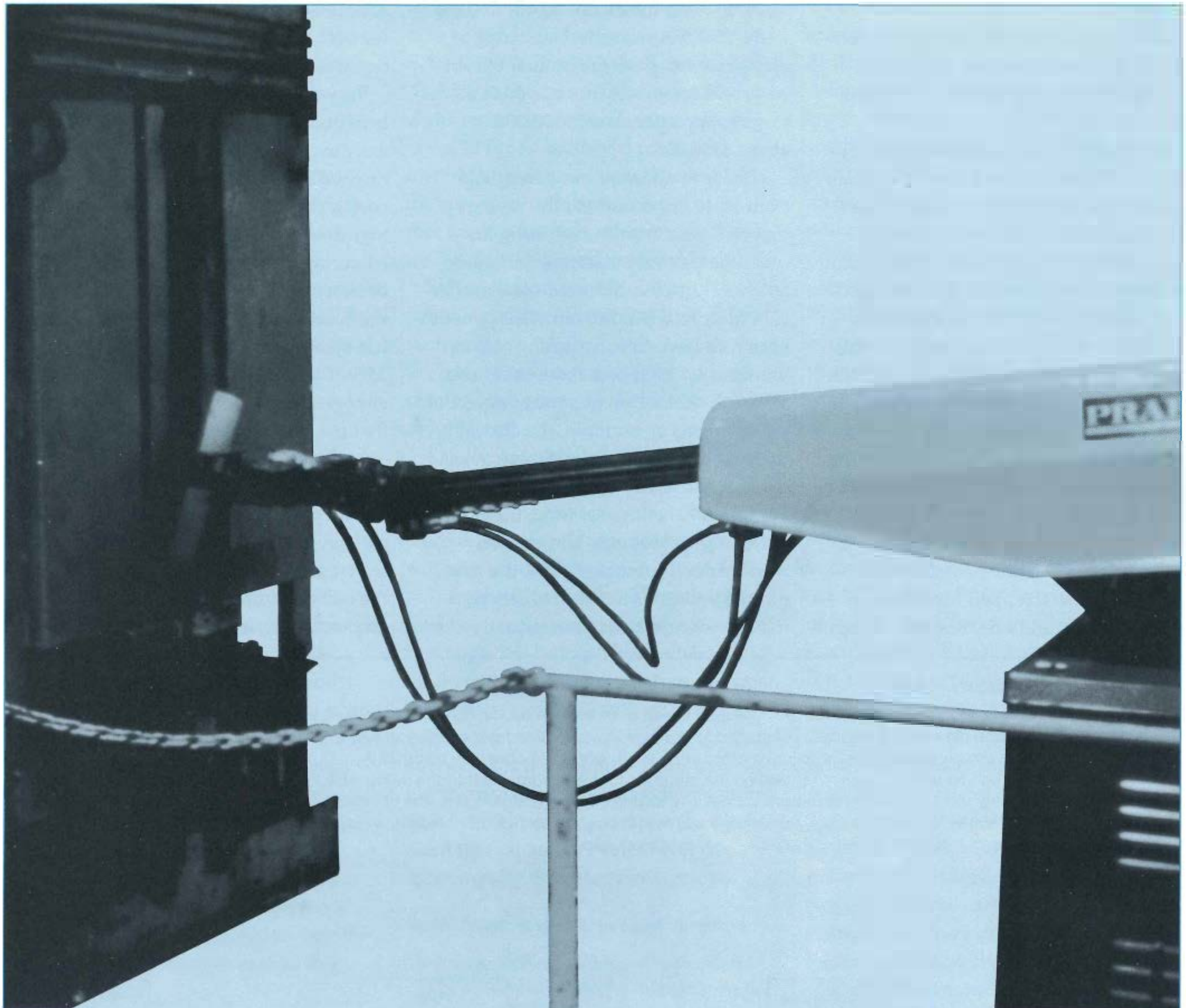
Looking ahead

Not all electric technologies offer all the cost savings just outlined. There are often trade-offs to be made. But when all the factors of production are taken into account, many of the new electrically

ENERGY-SAVING MOTOR DRIVE

The variable-speed drive, a device that alters the operating speed of an electric motor, can conserve energy in a wide range of industries. For example, in a chemical plant using standard constant-speed drives to pump fluid from one vessel to another (top), flow can be reduced only by throttling a valve downstream, while the pump motor continues to work (and consume electricity) at full power. With a variable-speed drive (bottom), flow can be reduced by simply feeding the pump motor less energy so that the pump works more slowly. With about 60% of all industrial electricity use attributable to motors, cumulative savings could be significant. The chemical, paper, and food-processing industries are prime candidates for this technology, and in the textile industry, nearly 70% of companies responding to a recent survey had added variable-speed drives to their process machinery over the last three years.





Manufacturers are showing rapidly growing interest in the productive potential of so-called soft tooling, where the motions and functions of versatile machines are controlled by sensors and computer codes. Robotics will open the door to the immense power of the microprocessor in directing the manipulation of material and the production of complex parts.

based processes look very competitive indeed.

General Motors Corp., a market leader that already consumes over 1% of all the electricity sold to industry, is moving rapidly toward increased electricity use. The big automaker is focusing on electrification of high-temperature processes, such as melting, die casting, heat treating, and forging of metals—applications that are now fueled about 75% by gas and only 25% by electricity. The estimate is that electricity will capture 60–70% of the company's high-temperature process market within the next 10 years. The reasons given, besides the expectation that electricity prices will rise less rapidly than gas prices over that period, are a potential for lower materials losses and labor costs, reduced factory floor space, and environmental benefits.

Will what is good for General Motors be good for the nation? The cost-cutting trend toward industrial electrification does indeed seem to offer many U.S. industries a chance to boost their competitive positions in world markets. Beyond that, electrification seems to answer some ongoing national concerns about the future of energy and the environ-

THE BIGGER PICTURE

Examining impacts of technological change from many perspectives is essential if the utility industry is to understand the real implications of large-scale trends. Helping industries identify and develop promising electricity-based processes is only the start of EPRI's interest in industrial electrification.

The Energy Management and Utilization Division, in charge of the basic screening process, must also keep an eye on the effects such new applications will have on the utilities' generation patterns—load shapes are likely to change with increased industrial demand. EPRI's Energy Analysis and Environmental Division takes a wider view in its research to model the effects of technological change and economic conditions on future industrial use of fuel and electricity; for example, the impact of fuel substitution or retrofitting programs. Work at EPRI's Energy Study Center takes a broad historical sweep, examining questions about the relationship of electricity used in industry to industrial productivity over time.

Such wide-ranging research will help prepare industry, utilities, and the marketplace for the changes likely to occur if industrial electrification continues to grow. □

ment. Electrified industries cannot be crippled by foreign oil cutoffs, given the abundant domestic resources available for generating power, although such industries are more vulnerable to, say, a coal strike. On the environmental side, concentrating heavy fuel-burning activities at power plants rather than scattering them among millions of factories simplifies the task of controlling impacts on the nation's air quality.

Electricity use in industry totaled about 2.4 quadrillion (10^{15}) Btu in 1981. That figure could more than triple by the year 2000, estimates Robert L. Mauro, program manager for industrial applications in the Energy Management and Utilization Division.

Many industrial products that are now made by combustion processes can be made by electric processes instead. The major constraint today is that certain common industrial operations are generally not yet economic to perform electrically. But the relative economics can change as conditions change, leading to a higher level of market penetration for electric process technologies and greater electricity use.

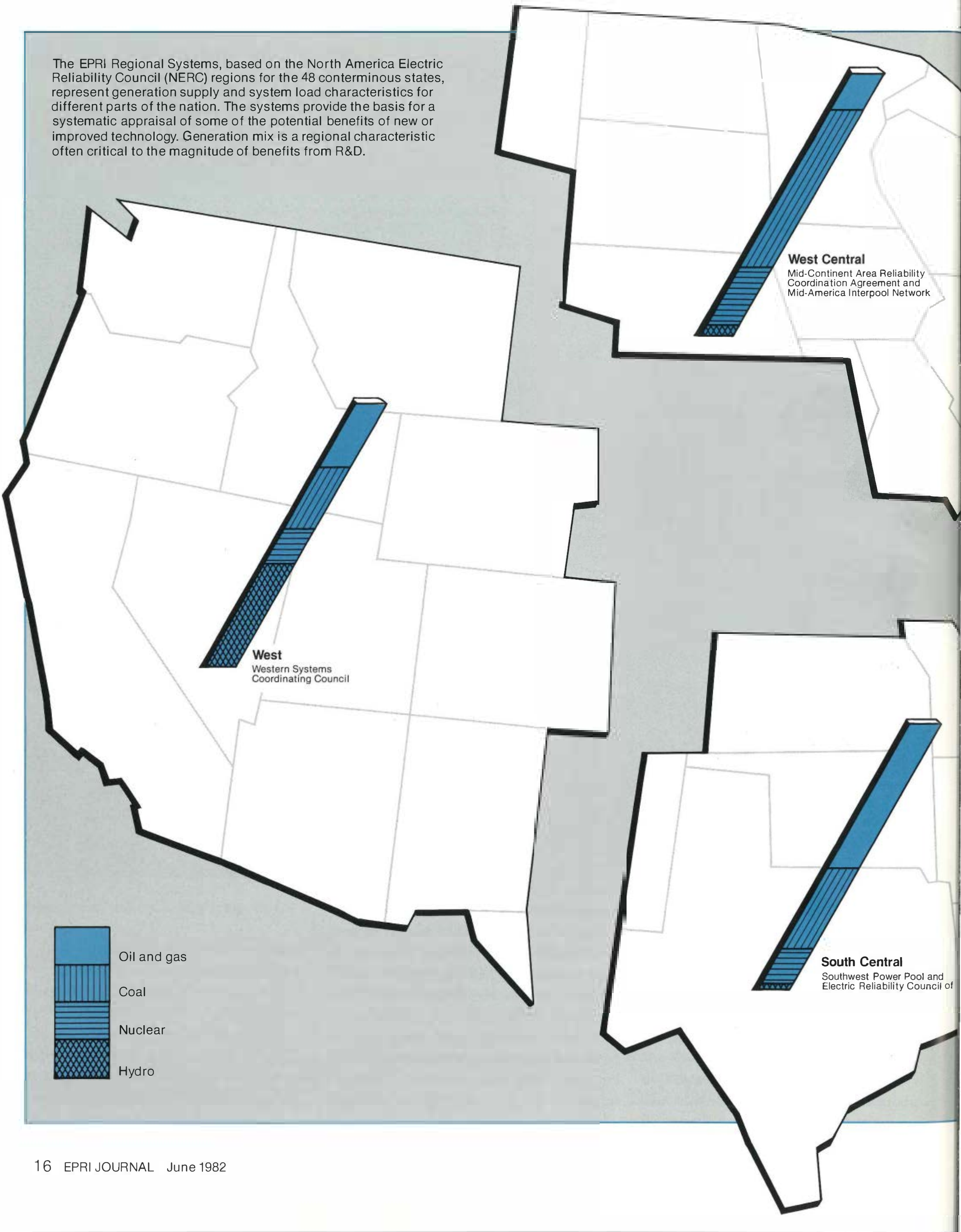
A vital link in this scenario is the computer. Mauro observes that the computer revolution has set the stage for widespread industrial electrification. Computers guiding industrial processes can make decisions instantly, and electrified processes can respond instantly to those decisions, without warmup or other lag time. Describing this natural match, Mauro says, "The microprocessor provides a medium for electric process technologies just as water provides a medium for fish."

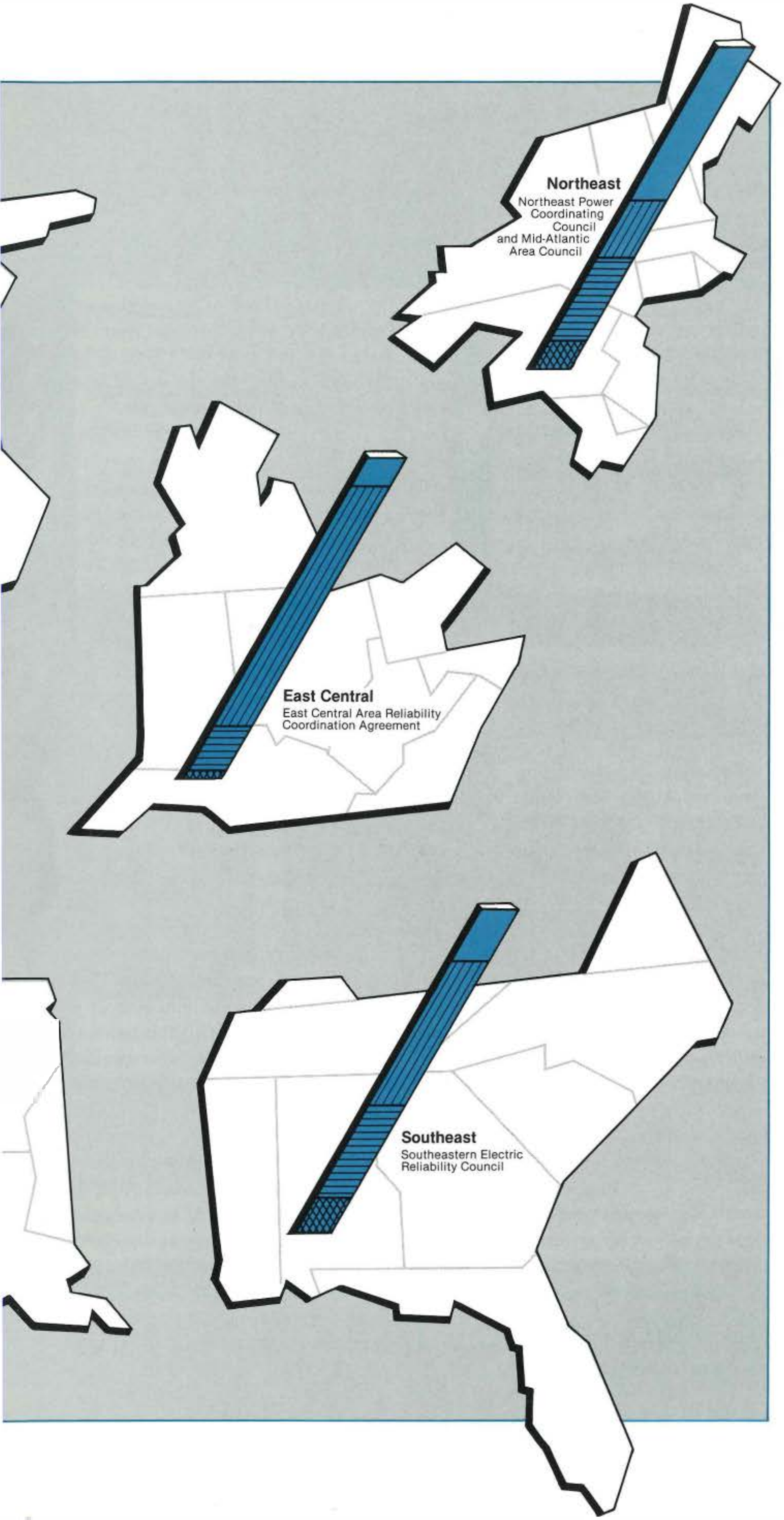
In addition, a computer can ask questions, follow directions, and function as a human work partner, offering its operator a soft interface with the process technology. This user-friendly control interface, plus the variable high-volume output that can typically be attained even in electric process facilities of modest size and cost, encourages small, decentralized manufacturing. Mauro notes the ironies of this trend, commenting that "the hardest of the hard technologies may bring us back to more human-scale enterprises."

Meanwhile, today's increasingly electrified industries may already be evolving a character quite different from what we are accustomed to. Philip Schmidt points out that although the impetus is economic, the consequences could be far broader, appearing "not overnight, but over a span of 20–30 years into the future." ■

This article was written by Mary Wayne, science writer. Technical background information was provided by Robert Mauro, Energy Management and Utilization Division, and Philip Schmidt, University of Texas.

The EPRI Regional Systems, based on the North America Electric Reliability Council (NERC) regions for the 48 conterminous states, represent generation supply and system load characteristics for different parts of the nation. The systems provide the basis for a systematic appraisal of some of the potential benefits of new or improved technology. Generation mix is a regional characteristic often critical to the magnitude of benefits from R&D.





THE VALUE OF 1%

How much is an incremental improvement in technical performance worth to the electric utility industry? And how are these benefits distributed among various regions of the country? These questions are being explored analytically through the EPRI Regional Systems methodology.

Benefits of research for individual utilities can be both obvious and spectacular. A new device or procedure that helps avoid a few days of downtime at a major generating facility can save a given utility and its customers millions of dollars in power replacement costs alone. However, determining the potential benefits of EPRI research must go beyond the experience of one utility to encompass diverse utilities throughout all regions of the country.

Variations in generation capacity mix, load growth, and other regional characteristics can have a profound effect on the magnitude of benefits resulting from R&D. To help assess those benefits for the entire country and to improve the evaluation of its own research programs, EPRI has developed a new analytic approach to this old problem. The strategy is to translate EPRI's R&D goals into specific utility benefits for six regions of the United States, called the EPRI Regional Systems (ERS).

The ERS approach is built on a data base that describes generation supply and system load characteristics for each of the six regions. In evaluation studies, new technologies and improvements are introduced into these reference systems to project potential capital and production cost savings in much the same way a utility would evaluate improvements for its own system.

Since the ERS data base and methodology was first introduced last July (P-1950-SR), it has been used to furnish new analyses for EPRI's *Overview and Strategy* and to assess the potential benefits of several EPRI project areas. These applications include a major study of nonexpansion alternatives to generation capacity additions, and assessments of baseload coal technologies, energy storage options, solar photovoltaics, small hydro facilities, and load management alternatives.

The ultimate goal of these EPRI evaluations is to see that every region benefits from EPRI research. This requires a portfolio approach to R&D planning, according to planning engineer James J. Mulvaney, the ERS project manager. "By taking regional factors into account through the ERS data base and methodology," he says, "EPRI will be better able to direct an R&D program that offers benefits for utilities throughout the United States."

Translating improvements into benefits

Relating technology innovation to potential regional and national benefits first requires that a way be found to relate broad R&D goals to industry cost savings. In EPRI's program, such research goals include developing or improving power generation technologies and other power system equipment, meeting environmental standards at minimum cost, developing new analytic tools and data bases, and increasing productive end use of electricity.

In the ERS methodology, these goals are first translated into parameters that can be analyzed quantitatively and that reflect industry priorities, such as generating-unit availability, heat rate, electrical system losses, and the cost of environmental control. Savings in production costs and capital costs can then be calculated for improvements in such parameters for each of the six ERS. National savings result from aggregation of the regional savings.

Regional differences arise from a number of causes. For example, regions that are especially dependent on oil or gas will place top priority on technology improvements and capacity additions that displace the uneconomic use of these fuels. Environmental issues also tend to be regionalized, with acid deposition and solid-waste disposal being particular problems in the East, while visible air quality and water availability are special concerns in the West. Transmission and distribution systems also differ markedly between eastern and western utilities.

To gain a broad perspective on EPRI program benefits while testing the effectiveness of the ERS approach, the Planning and Evaluation Division conducted a series of four studies based on 1% improvements in the key parameters mentioned earlier: unit availability, heat rate, electrical system losses, and environmental control costs. These studies take an intuitive, "what if" approach by asking how a 1% improvement in these parameters would benefit utilities in various regions of the country. The results, scheduled to be published in August in an EPRI special report titled *R&D Benefits Assessment—A Regional Approach,* showed that a 1% improvement in each area could result in a savings of from hundreds of millions to billions of dollars by the utility industry and its customers over the period from 1979 to 1985. Regional benefits, however, varied significantly.

To make sure the results of these studies would be credible, several conservative assumptions were made. In three of the four cases, only savings in production costs were calculated; in the fourth, savings in capital cost were included. Benefits were restricted to improvements in baseload capacity. Savings were estimated for the 1979–1985 period only, although further savings would accrue over the life of an improved plant.

These estimates of benefits do not include possible costs of implementation by utilities, as implementation costs depend on the particular technique applied to achieve the improvement. For example, there may be little or no cost associated with new operating procedures, and equipment that offers lower losses may not cost more than standard equipment. Retrofits to existing plant, however, may require additional expenditures. Naturally, these costs would be subtracted from the benefits when applied to specific R&D options.

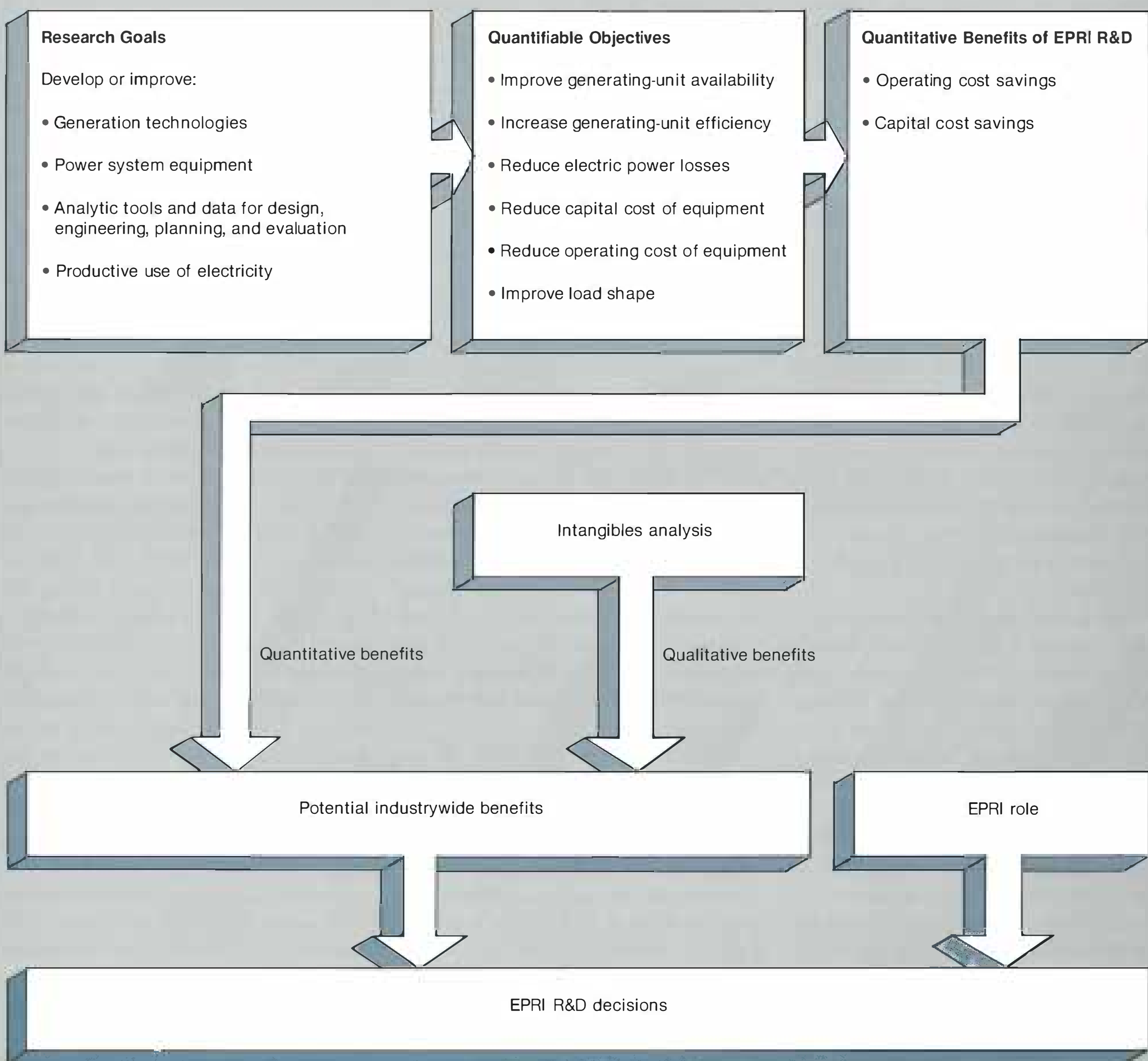
"It would be both wasteful and unnecessary to perform regional assessments of this sort on every individual project," Mulvaney concludes. "By addressing broad parameters of utility significance, results of the four 1% improvement studies can be applied in estimates of potential benefits for many projects throughout the Institute. This not only is more efficient but ensures that such benefits estimates are carried out on a consistent basis."

Higher availability

In the first ERS study it was determined that production cost savings from a 1% availability improvement in baseload coal and nuclear generating units would be $2.2 billion nationwide over the seven-year period. Regional differences are great, with maximum-to-minimum benefit ratios of 25 to 1 for coal and 11 to 1 for nuclear. These differences are attributable to three main factors: the mix of

EPRI REGIONAL SYSTEMS ANALYSIS AND THE DECISION PROCESS

The EPRI decision process for focusing R&D effort is multifaceted, including assessment of the potential benefits, both quantitative and qualitative, of improved utility technologies and methods. Decisions are also dependent on an assessment of the role EPRI can play in assisting utilities to achieve these benefits. Industry advisers contribute to both these assessments. The EPRI Regional Systems analysis, detailed at the top of the diagram, quantifies the capital and operating cost savings of technical improvements that might result from EPRI R&D.



fuels that are displaced by increased baseload output, production costs of the improved generation, and the amount of generation capacity that is improved. The Northeast, Southeast (mainly Florida), South Central, and West regions, with heavy dependence on oil or gas, would benefit most.

Several EPRI programs are dedicated to increasing the availability of nuclear and coal generating units. For nuclear plants, research is being conducted to find faster ways of loading fuel and handling decontamination and to address numerous specific problems, like tube denting, leaking valves, and feedwater pump failures.

In recent years large fossil fuel plant availability has been decreasing for a variety of reasons, including the addition of complex environmental control systems, use of lower-quality fuels, and operation under load-following conditions. A variety of EPRI programs are aimed at counteracting this trend by helping to increase plant availability by as much as 5%. Even if partially successful, this research could yield benefits substantially greater than indicated by the study based on 1% improvement.

One project that could contribute to such a benefit is studying scale damage to turbine blades. When iron oxide scales flake from the interior surfaces of steam superheaters or piping in a power plant, they can be carried into turbines and rapidly erode the blades. This damage may require early repair and can substantially reduce the availability of a plant's steam turbines. Under EPRI contract, Foster Wheeler Development Corp. has developed a process of reducing the growth of iron oxide scale by two-thirds. To effect this reduction, metal surfaces are exposed to a sodium chromate solution for 30 hours, which results in formation of a chromium-enriched layer that strongly resists oxidation. The process is currently undergoing evaluation in a utility plant.

In another availability study, EPRI-sponsored research has identified boiler feed pumps as one of the major causes of unscheduled outages at large fossil fuel power plants. Data gathered on the operating histories of 1204 of these pumps provided the basis for establishing new criteria for selecting them and thus improving plant availability. Tampa Electric Co. has used these data to evaluate vendor designs for new pumps at the company's Big Bend Four generating station. As a result, downtime caused by the pumps is expected to decrease from an average of 83 hours a year to around 48.

Improved heat rate

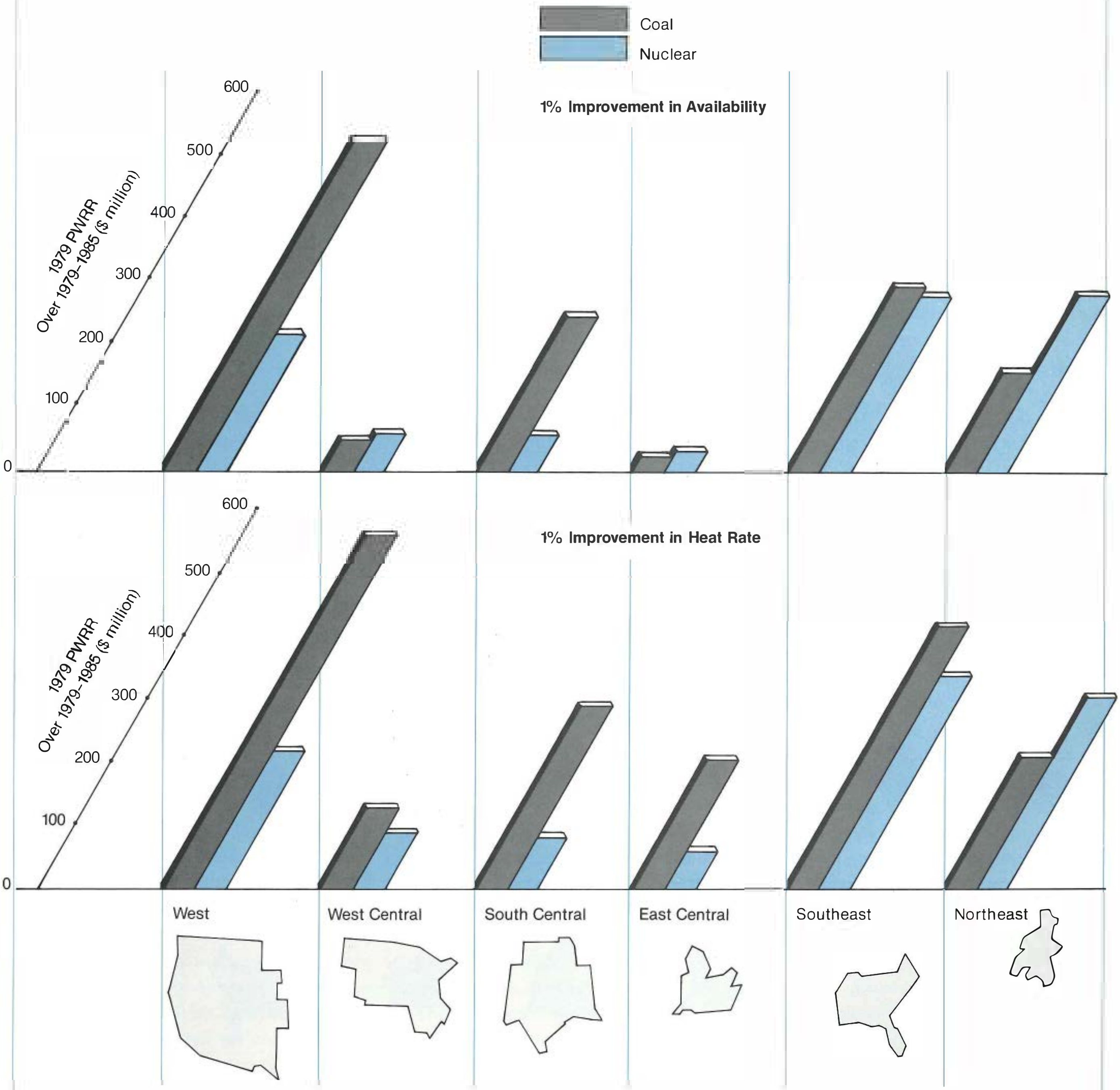
Improvements in the efficiency with which heat is used in power plants to produce electricity can be implemented according to two strategies. Depending on the technology involved, a utility could attempt either to increase the electric output of a plant for a given amount of fuel input or to decrease the fuel required to produce a given amount of electricity. The increased output strategy generally gives significantly better cost savings because extra power from baseload plants means that more expensive power from peaking and intermediate plants is displaced. That is, increasing the electricity generated per unit of coal or uranium can save oil. Reducing the baseload fuel required to produce a unit of electricity, however, saves only the cost of the much cheaper fuel.

The ERS study showed that a 1% improvement in baseload plant heat rates could result in a nationwide savings of $2.8 billion in production costs for the increased electric output strategy and $0.9 billion for the reduced fuel input strategy. Regional differences for both strategies depended on the amount of capacity improved. For the increased output strategy, differences also depended on the mix of fuels displaced, as in the availability improvement study. For the increased output strategy, the maximum-to-minimum benefit ratios were 7 to 1 for nuclear and 5 to 1 for coal; for the reduced input strategy, these ratios were 4 to 1 and 3.7 to 1, respectively. Benefits were largest for increased output from coal-fired plants in the Northeast, Southeast, South Central, and West, where reliance on oil or gas is high.

Improvement in the heat rate of a plant is usually related to improvements in other areas, such as availability or environmental control, so few EPRI projects are concerned with heat rate alone. For example, reheating the exit gases from a plant scrubber to prevent condensation in the ductwork can create a substantial heat rate penalty (150–250 Btu/kWh added to a nominal heat rate of 10,000 Btu/kWh). A completed EPRI project has demonstrated that this penalty can be reduced by using recycled heat. The process involves taking energy from hot inlet gases of the scrubber and transferring it to the cool exit gases. Building the facilities to perform cyclic reheating adds to the initial cost of a plant, but over the life of a plant the levelized net savings can be equivalent to more than a mill per kilowatthour of electricity sold.

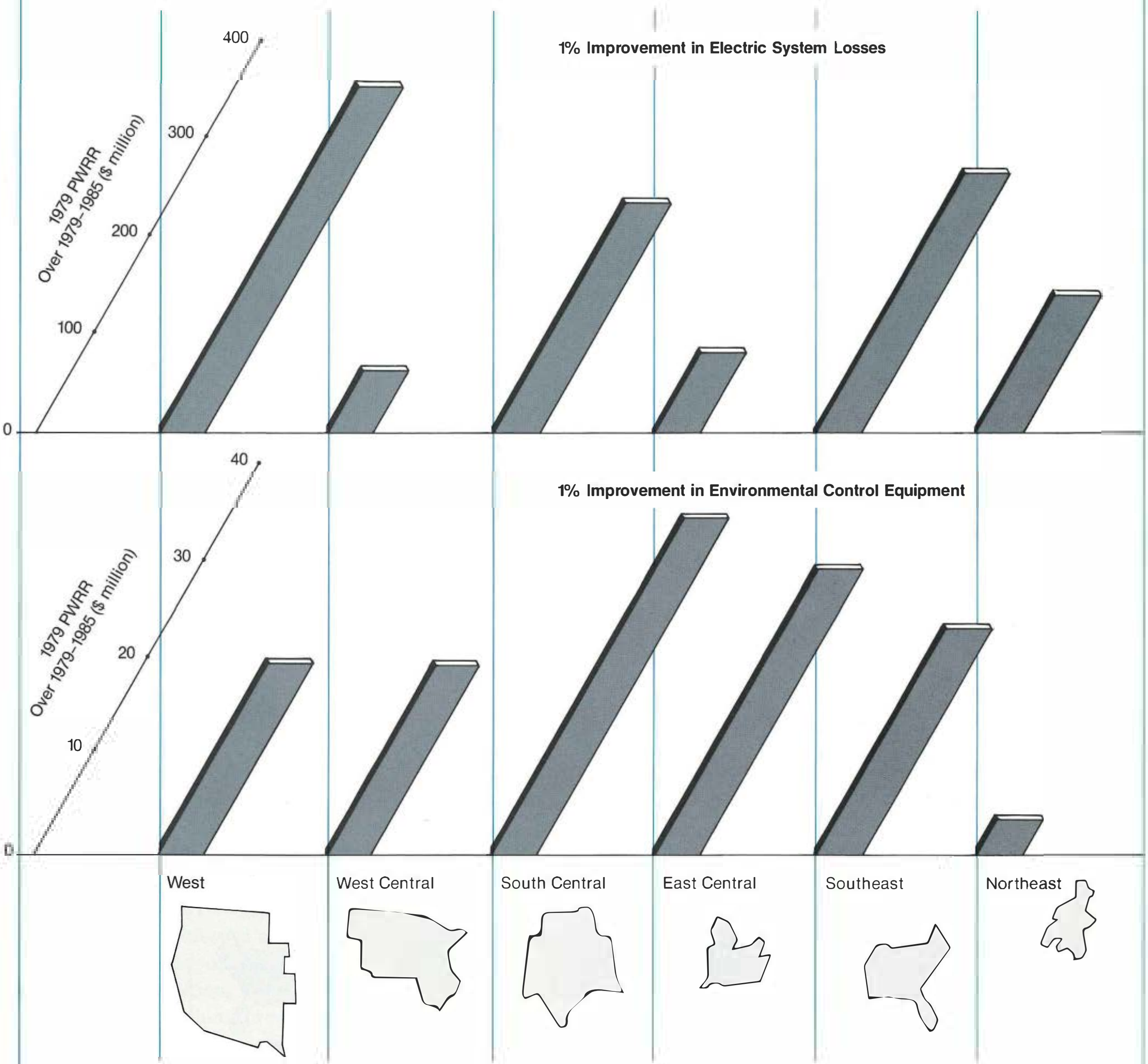
The efficiency of new conventional pulverized-coal power plants provides another example of the interdependence of technology improvements. The heat rate of such plants has fallen off during the last decade largely because of environmental restrictions and controls. Highest efficiency of new plants now averages about 36%, compared with an average of 38% for the most efficient plants in the 1960s. Efficiency (heat rate) can be improved by increasing steam pressure and temperature, and thermal losses can be reduced through waste heat recovery and better equipment efficiency. EPRI has conducted research to determine the optimal design for advanced plants with improved heat rate, which could feature turbines and boilers designed for improved load-following, nickel-chrome alloys to reduce corrosion, more efficient fans and drives, and integrated environmental controls. Such a plant should have a heat rate that is 10% better than today's most efficient units, while providing increased availability and reduced emissions.

A 1% improvement in the availability of coal and nuclear baseload plants is valued at $2.2 billion nationwide over the seven-year period (1979 present worth of revenue requirements). The distribution of these benefits by region and fuel source is shown below.



A 1% improvement in the heat rate of coal and nuclear baseload plants is estimated at $2.8 billion over the seven-year period (1979 present worth of revenue requirements). The distribution of benefits, shown above, assumes an increased electric output for a given amount of fuel input. Not shown is the case where fuel requirements are reduced for a given electric output; savings here were estimated at $0.9 billion nationally.

Potential savings for reducing electric transmission and distribution losses from 8% of total system demand to 7% are valued at $1.1 billion nationally over the seven-year period (1979 present worth of revenue requirements). The distribution of these benefits regionally, shown below, assumes loss reduction associated with load added after 1979 only.



A 1% improvement in both the capital and operating costs of flue gas desulfurization systems and electrostatic precipitators is valued at $127 million over the seven-year period (1979 present worth of revenue requirements). Distribution of these benefits regionally is shown above.

Lower electrical system loss

Energy losses that occur between a power plant and a customer's meter range from about 7% to 10% of total system demand among various utilities, with a national average of about 8.3%. For this ERS study, the benefits of reducing electrical system losses from 8% to 7% were calculated for new load growth between 1979 and 1985; that is, losses for load added after 1978 were reduced, while losses for load that was existing in 1978 remained unchanged. The potential nationwide production cost savings of such a reduction would be $1.1 billion for the 1979–1985 period.

Benefits again varied greatly by region, with a ratio of maximum to minimum savings of 5 to 1. These variations resulted from two major factors. First, reduced system losses translate into incremental reductions in load, as seen by the generation system. Savings are thus greatest in those areas with the highest incremental production costs—the Northeast, Southeast (mainly Florida), South Central, and West. These regions are relatively dependent on oil and gas. Second, since in this study loss improvements are introduced only with new equipment associated with load growth, benefits are greatest where load growth is highest—that is, in the Southeast, South Central, and West. Benefits will be even greater where existing equipment is retired and replaced with new equipment having lower losses.

Reduction of electrical system losses can best be understood in terms of new technology being developed that will accommodate load growth. One promising new technology that may lead to substantial reductions in electrical system losses in the future is a transformer core made from amorphous metal. This material is produced by cooling a molten alloy so quickly that no crystallization occurs during solidification. The random atomic structure that results has lower energy losses when subjected to a changing magnetic field and also has lower losses from induced eddy currents. A typical 25-kVA distribution transformer has continuous core losses of about 120 W; the target material of EPRI's current program with Allied Corp. would have core losses of only 45 W. The potential energy savings from using this technology could amount to $200 million per year.

Reduced costs for environmental control systems

EPRI's R&D efforts in this area are directed toward providing utilities with options they can use to meet current and future environmental control requirements at minimum cost. The fourth ERS study focuses on just two such options—flue gas desulfurization systems and electrostatic precipitators. Because the installation of such systems now adds significantly to the initial cost of a new coal-fired power plant, both capital and production costs were considered.

The results showed that a 1% reduction in these costs would lead to a $127 million nationwide saving for the 1979–1985 period. Although this figure is substantially less than that for the other three studies, the potential for improvement is much higher, perhaps 10% or higher overall. Regional differences depended on the amount of coal-fired capacity to be added over the 1979–1985 period, so some regions might expect twelve times the benefits of other regions. Regional differences in coal additions are mostly because of load growth variations.

Although only two particular types of control devices were considered in this study to provide a convenient estimate of potential savings, future environmental control is likely to depend on a variety of devices used in some optimal configuration. The following examples illustrate the breadth of EPRI's efforts to provide utilities with a greatly improved choice.

The Chiyoda Thoroughbred-121 process provides utilities with an alternative to the conventional limestone scrubber. The process uses a jet bubbler reactor to remove 90–95% of the sulfur dioxide in stack gases, while producing a marketable by-product, gypsum. EPRI sponsored an eight-month evaluation of the process at Gulf Power Co.'s Scholz plant, which tested the operating limits of the system and verified vendor claims about its superior efficiency and reliability. On a new 1000-MW coal-fired power plant, the Chiyoda process may save $6 million a year in operating costs.

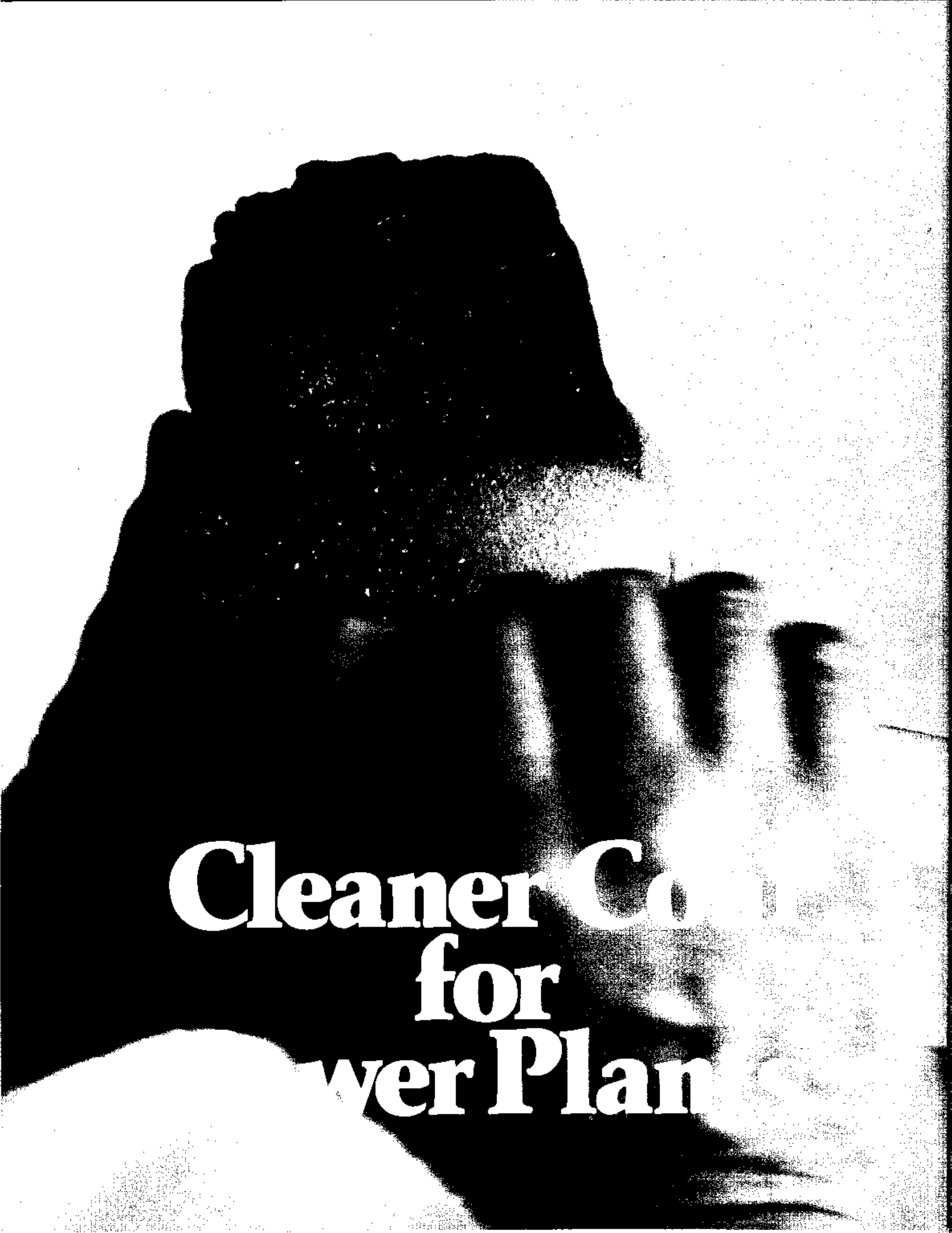
To help utilities meet New Source Performance Standards for particulate emissions, EPRI has sponsored a major test of fabric filters (baghouses) at its Arapahoe Emissions Control and Test Facility. Preliminary tests have evaluated the effectiveness of distribution devices to achieve uniform flow of dust and gas. Some problems of startup and shutdown have also been identified. The reliability and economic feasibility of the baghouse concept have been demonstrated by fabric filters installed at Colorado-Ute's Nucla station.

Toward an R&D portfolio

The studies of 1% improvements in the four key parameters show the very large potential benefits that can accrue on a national scale from technologies and improvements developed through EPRI research. They also reveal the importance of taking regional differences into account when planning and evaluating future R&D. By using ERS analyses, EPRI project managers will be in a better position to communicate benefits of present research results to utilities, and program planners will be better able to shape and direct a diverse portfolio of R&D on a national scale.

Richard Zeren, director of the Planning and Evaluation Division, concludes that "assessing the potential regional benefits of EPRI research is a key new element of our decision making. The ERS data base and method assists our contractors and our staff in quantifying the value of our research goals so that we can balance our R&D portfolio to serve the diverse needs of EPRI member utilities—and their customers—throughout all regions of the country." ■

This article was written by John Douglas, science writer. Technical background information was provided by James Mulvaney, Planning and Evaluation Division.


Cleaner Co
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Minerals in the primeval vegetation that decomposed to form coal are still contained in coal deposits, along with other minerals left by water flows over the eons. A higher percentage of these minerals is showing up in mined coal. In fact, over the last 10 years, this greater mineral content has meant that the average quality of coal burned in power plants has fallen in terms of its energy-producing potential from 11,750 Btu/lb to 10,600 Btu/lb. Over the same period, the availability of U.S. electric generating plants has dropped by an average of about 10% because of a steady rise in plant outages.

These parallel phenomena are often believed to be related; consequently, many utilities are investigating the characteristics of their coals. Coal quality in general has deteriorated because of changes in mining methods and regulations. Mine productivity is down, and this decline has hastened the spread of mechanized mining methods, which discriminate less precisely between coal and mine roof and floor.

Although power plant boilers can be designed to burn almost any grade of coal, the firing of coal that is inferior to that specified results in an increased outage rate. Many boilers on-line were designed for higher-quality coal than they are now firing, and researchers are trying to determine how much the performance of these boilers would improve if coal quality were upgraded by coal cleaning to the level originally specified. Although several hundred commercial coal-cleaning plants exist, their processes cannot separate all the Btu (energy-producing content) from the mineral matter, and therefore about 5% of the Btu are disposed of with the refuse.

Five years ago, EPRI saw the urgent need for a scientific approach to upgrading the quality of coal and coal cleaning for power plants. After consulting numerous experts in the field, EPRI began to plan construction of an advanced coal-cleaning test facility. The project had three objectives: to characterize steam-coal cleanability on a national basis; to develop and test new equipment and processes; and to train coal-preparation engineers and operators.

The $15.2 million facility was completed last year near Homer City, Pennsylvania, and is being operated by Kaiser Engineers, Inc. Cosponsoring the facility with EPRI are Pennsylvania Electric Co., New York State Electric & Gas Corp., and the Empire State Electric Energy Research Corp. Through services offered by the facility, electric utilities can find out which cleaning processes are the most effective for their particular coal.

Generation costs

Even though the purchase of coal incurs the largest chunk of the operating expenses at a coal-fired plant, the cheapest coal does not always result in the lowest-cost eléctricity. Low-cost, high-sulfur coal, for instance, can be a financial liability as far as controlling stack emissions is concerned.

Most coal delivered to utilities contains impurities. These include certain minerals inherent in the coal, rock from the roof and floor of the mine, and pyrite, an iron and sulfur compound. Transporting and handling these inorganic minerals along with the organic, heat-giving coal adds unnecessary expense, and their interaction with the power generation system imposes further problems. During combustion, for example, minerals create extra ash in the boiler. Mineral matter converts to slag, which coats boiler surfaces and acts as insulation, inhibiting proper transfer of heat to the water in the boiler tubes. Sulfur in the coal burns during combustion and forms SO_2 and SO_3.

Mineral matter in coal exacerbates costs of maintenance and outage not only in the boiler system but also in the emissions control systems. Ash, besides corroding, erodes fans, ducts, and tubes—having an effect like a light sandblasting. Last, but not least, of the problems associated with the inorganic content of fuel is the disposal of ash, which may take up valuable land space.

The cumulative costs of transporting, burning, removing, and disposing of stowaway impurities in coal continue to bloat the overall costs of electricity generation. Because impurities promote wear and maintenance problems, they reduce total annual operating time for a power plant and can take a slice off maximum capacity, both of which translate into economic losses. Stacked on top of these costs are possible expenditures for the purchase of higher-cost electricity from other sources during plant downtime, and even the need to build new capacity as older units wear out or are derated because of deterioration in coal quality.

Nicholas Esposito, now a project manager at Jersey Central Power & Light Co., was formerly a site manager at the Homer City plant of Pennsylvania Electric Co. A coal-cleaning plant was built to comply with EPA sulfur emission regulations, but Esposito, in retrospect, sees that another major benefit accompanied the change.

Two of the three Homer City units had design loads of 650 MW but had been restricted to 550 MW because of high ash levels and boiler slagging. When the cleaning plant reduced ash levels in the coal, these two units regained 30 MW each to achieve a level of 580 MW. In addition to moving toward compliance with the emission regulations, according to Esposito, the company effectively saved $60 million that might have been necessary to build 60 MW of generation replacement. Esposito adds, "EPRI sponsored some studies that helped us resolve some major problems in redesigning the coal-cleaning plant at Homer City."

Apart from the savings in operating costs that accrue from coal cleaning, a net increase in Btu/t of coal will also be possible through better cleaning. In conventional cleaning plants, 2% of the Btu are rejected with coarse coal and 3% with fines. In effect, 5 t out of every 100-t load are lost. Taking an average price of coal as $35/t, the real price rises to $36.75/t. Added to that is the cleaning cost itself, $2–$6/t of clean coal. Nevertheless, it has frequently been economical in the past to dispose of the fines because their collectively large surface area causes them to hold a high percentage of moisture. Moisture in coal not only creates weight and makes transportation more costly, but when coal is burned, it causes combustion heat to be dissipated through evaporation. In any coal supply, 15–25% could be fines, so the need for both effective separation from mineral matter and better dewatering methods is evident.

The test facility

Unlike commercial cleaning plants, EPRI's test facility is not dedicated to a single flowsheet or sequence of cleaning processes but is built to accommodate five basic flowsheets. In fact, with the addition, subtraction, or change in sequence of individual processing units, up to 50 different flowsheets can be set up to simulate a particular utility cleaning plant.

Each processing unit, such as a cyclone or filter, is flexible in that it can be adapted to process different quantities and sizes of coal. This means that fewer test units are required in the facility to simulate a wide range of cleaning-plant designs, thereby keeping testing costs down.

The processing units at the facility are of commercial size, so test results from the facility will be directly applicable to utility-scale cleaning plants.

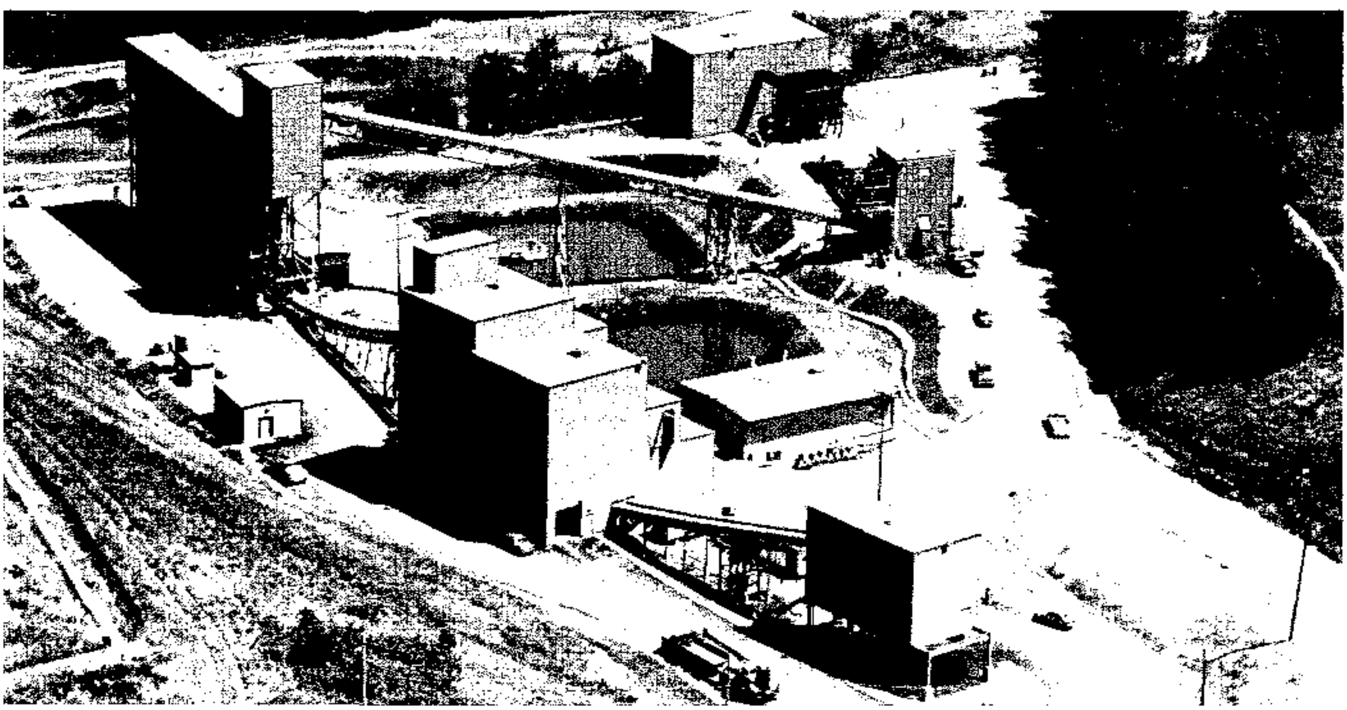
Electric utilities are invited by EPRI to participate in the test program by contributing run-of-mine coal samples of about 1000 t to the facility. Coal can be experimentally cleaned in up to five process sequences by running a fraction, say, 200 t, through a particular flowsheet at a time.

Participants will receive a reliable estimate of their sample's cleaning characteristics and a direct comparison between run-of-mine and clean coal. This estimate will be more valid than one based on a small laboratory sample, which is the general practice.

As Douglas Trerice, manager of the EPRI facility, explains, "If a utility is interested in building a coal-cleaning plant or understanding the cleanability and cost of cleaning its coal, the lowest-risk path is to test its coal at the test facility. That way, the utility is assured that the large sample really represents its coal reserves and that the coal will be tested in commercially available processes, using equipment now on the market."

The clean-coal samples can be transported to test combustors elsewhere for determination of burning characteristics. After test cleaning and test burning, a utility should be able to judge the effect the clean coal will have on an existing boiler or how to design a new boiler to best burn the clean coal.

Robert Frank, project manager for coal cleaning and for performance and reliability at the Tennessee Valley Authority, plans to have a large coal sample delivered to the EPRI test facility soon. The coal, which is mined close to TVA's Paradise plant, has a high clay content that makes fines very sticky and more difficult than most coal to clean. Frank says that



Coal-burning utilities from all over the United States can send samples of their coal to EPRI's Coal Cleaning Test Facility near Homer City, Pennsylvania, for cleanability characterization at commercial scale. From these analytic data, utility engineers and operators learn the type of cleaning circuit best suited to the unique characteristics of their coal supply and obtain clean coal samples for combustion testing.

up to now the cleaning of fines in froth flotation cells has been more an art than a science. "We believe that the EPRI test facility can give us some guidance in solving problems in the fine-coal circuit for these western Kentucky coals. There's more than one unknown in the puzzle."

Besides providing data on the cleaning characteristics of coal and on the design of processing units and systems, the test facility will introduce more-accurate procedures for sampling coal. Other new instrumentation includes devices for measuring the flow and density of slurries and an on-line analyzer for determining ash and sulfur concentrations. A national coal-quality data base will also be established that could eventually hold unique facts, such as the potential for sulfur reduction in various steam coals of national importance.

Cleaning processes

All processes now available for the physical cleaning of fine coal are housed at the test facility. Because the emphasis is on practical application and improvement of existing technology, chemical cleaning processes, which are at the research stage, are not included.

When coal arrives at the test facility's receiving station (by truck and rail), the first of 54 samplers throughout the plant removes an amount up to 10,000 lb of coal for washability analysis. Then the coal, whether hard anthracite or softer bituminous or lignite, is crushed at rates up to 100 t/h to a top size between ¾ and ¼ in, is sampled again, and stored in one of five 100-t bins.

Coal can be stored according to specific seam source, mine, or size or as a blend. The blending is an automatic process in which a conveyor belt with a mechanical tripping device travels between bins, depositing specific amounts of coal as a mix. Weigh feeders measure and control the amount taken from the bins as feed to the test plant.

Once laboratory staff have tested the raw coal for washability by immersing it in fluids of different specific gravities and observing what percentages float or sink, the rest of the coal can enter the plant at up to 20 t/h to follow the most appropriate of the five flowsheets. These will include some combination of coal-and-mineral separation processes, for instance, heavy-media cycloning, water-only cycloning, froth flotation, and tabling. Supporting equipment consists of screens, a classifying cyclone, thickening cyclones, centrifuges, a disk filter, and a thickener. To change flowsheets, the sequence of operations can be altered by diverters installed between operating units.

Slurry or solids samplers are positioned on each unit to sample all inlet and outlet flows. These samplers can be activated simultaneously to take snapshot samples of all material in the plant at a single moment or they can be programmed individually. The emphasis is on advancing the science of accurate and representative sampling. Existing cleaning plants are "blind" to the amount and composition of the material going into and coming out of their systems, and as yet have no slurry samplers. This year at the facility, sampling data will form the basis for computer models to help utilities predict the efficacy of different cleaning procedures.

A coal sample that has been crushed to a top size of ¾ in is first sprayed with water and vibrated on a 0.5-mm-screen deck. On average, about 25% of the coal passes through the deck as fines, while 75% remains on the deck to be processed through the heavy-media cyclone, the water-only cyclones, or the concentrating table. The fines go to the water-only cyclones and the froth flotation cells.

The heavy-media cyclone, which separates coal and mineral matter larger than 0.5 mm, is a 14-in-diam cone-shaped container with a vortex pipe leading out of the top and an outlet pipe at the bottom. The mixture of coal and mineral matter is first added to a suspension of water and magnetite (iron oxide ground to a very fine size) and is then spun in the cyclone. The heavy magnetite medium increases the specific gravity, or density, of the fluid so that the less-dense coal floats and can be separated from the heavier mineral matter.

When the coal slurry is fed into the heavy-media cyclone and spun, the magnetite and mineral matter gravitate to the sides of the cyclone and slide to the bottom, where they exit. The coal whirls down at first, but as it is a lighter material, it is drawn upward by the vacuum of the vortex action of the cyclone to the outlet at the top.

The specific gravity of the suspension can be increased from water's nominal value of 1 to the desired cleaning level by adjusting the amount of magnetite. Since coal's specific gravity is between 1.2 and 1.5, the water and magnetite medium is usually kept between 1.3 and 1.8 to ensure that the coal will float; the mineral matter's average specific gravity is about 2.7, so it sinks in the magnetite medium.

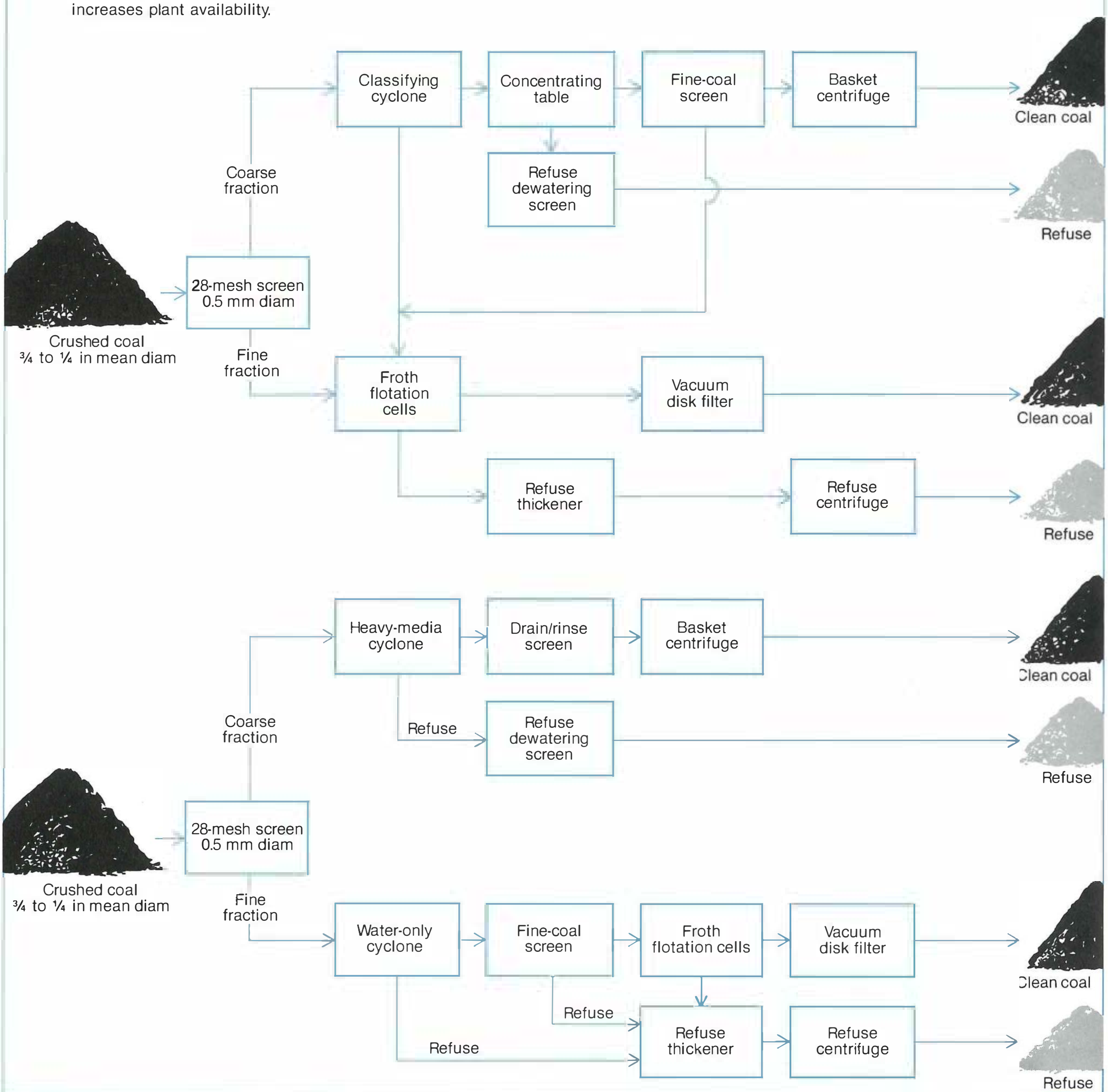
After leaving the cyclone, the magnetite is washed off the coal and refuse so that it can be reused. Refuse is dewatered (both disk filter and centrifuges can be used) and sent to disposal. The coal exits to a basket centrifuge for dewatering.

The concentrating table is designed to separate the larger-size fraction of coal and mineral matter by a method similar to panning for gold. It consists of a large, flat, tilted table with a grooved surface. The table is continuously vibrated while a stream of coal and water flows down its surface from the high side. The lighter particles of coal tend to concentrate on top of the mineral particles in the grooves and so are swept down the table to a collection area. The heavier mineral particles remain in the grooves and work their way to the side of the table, where they drop off to a refuse area.

The water-only cyclones are similar in shape to the heavy-media cyclone with a side inlet and outlets at top and bottom. The principle of separation is also the same—when the coal-and-water slurry enters the cyclone in a rapid flow, the heavy mineral particles gravitate to the bottom outlet, and lighter coal particles

THE COAL-CLEANING CIRCUITS

The three generic processes in coal cleaning are size classification, the cleaning process (separation from mineral refuse by a liquid medium), and dewatering/drying of clean coal for storage and of refuse for disposal. Five flowsheets are in place at EPRI's test facility, although numerous others can be simulated by simple piping changes. The two examples shown here represent only some of the circuits available. In the first flowsheet, coarser coal is cleaned on a concentrating table; finer coal goes to a froth flotation cell for separation from fine refuse in a method based on differences in the surface properties of coal and refuse. In the second flowsheet, the coarser fraction of coal is spun in a heavy-media cyclone, while the finer fraction goes through water-only cyclones and then proceeds through the froth flotation process. In both flowsheets, coarse coal is dewatered in a basket centrifuge and fines on a vacuum disk filter; coarse refuse is dewatered on screens and fine refuse in a centrifuge. Because the cleaning process is water-based, clean coal has a higher moisture content than raw coal. But clean coal compensates by containing less ash and sulfur per ton, which cuts down on wear of boilers, ductwork, fans, and flue gas emission controls and therefore increases plant availability.



are flung through the top outlet. The water-only cyclones can be used for cleaning either coarse or fine coals in one or two cycloning stages. However, the finer the coal, the more difficult the cleaning process.

Froth flotation is the method most often used to separate very fine coal from minerals. The slurry is pumped into 20-ft^3 flotation cells after being agitated in a small storage tank where the percentage of solids in the slurry can be monitored for consistency to ensure the cell's efficiency is at its highest. Two banks of four flotation cells allow investigation of a wide range of flotation schemes.

The factor that differs from other coal-cleaning units is that oil is added to the slurry; because of its chemical similarity to coal, the oil adheres easily to the coal but not to the mineral matter. The oil allows air bubbles that have been injected into the flotation cell fluid to attach themselves preferentially to the coal particles. The fines then become so buoyant that they rise to the surface of the fluid and can be skimmed off the top, leaving the mineral particles behind. After the coal has gone through the fines cleaning, it is dewatered on vacuum filters.

Even with dewatering, clean coal ends up with a higher moisture content than raw coal. However, the trade-off is that it has a lower ash and sulfur content and more Btu per ton. This means that high-ash, high-sulfur Appalachian and U.S. interior coals become more attractive because flue gas emissions can be lessened with precombustion cleaning. The Clean Air Act Amendments of 1977 allow any combination of precombustion desulfurization of coal and postcombustion gas cleanup to meet SO_2 limits, so some utilities could find coal cleaning essential if they anticipate new local air emission regulations or contemplate the conversion of oil-fired plants to coal.

"The quality of the coal leaving any coal-cleaning plant depends not only on the coal itself but also on the flexibility of process control," says Trerice. EPRI's facility will allow development of completely automated coal-cleaning systems. All motors and instrumentation at the facility are connected to a digital computer that activates startup and shutdown and monitors the recording of operating data. This computerized system makes modifications in process control simpler than conventional systems. It eliminates the time lags typical in most cleaning plants between the time when corrective actions are needed and the time they are implemented with the computerized system, allowing an estimated 5% increase in recovery of Btu per ton of coal.

Comparative cleaning levels

Further savings have been demonstrated in a recent EPRI study of seven hypothetical coal-fired power plant systems, each using one coal from a particular mine and three levels of coal cleaning. Level A entails crushing and screening, with rejection of coarse mine debris. Level B represents the cleaning of coarse coal only (larger than ¼ in diam). Level C involves intensive cleaning—the coal is broken into two or three size fractions, each of which is cleaned separately.

Results of the study are encouraging. For each 1000 MW (e), the annual cost savings in coal transportation, handling, and waste disposal were in the range of $1–$7 million. The ash content in the coal shrank by between 10% and 70%, and 20–60% of the sulfur was removed.

The capital requirement for the Level B (partial) cleaning plants was about 2% of the total capital cost of the 1000-MW (e) coal-fired power plants (in mid-1978 $). When using Level C (intensive cleaning), the share of power plant capital cost was 3–5%.

Frederick Karlson, manager of EPRI's Coal Quality Program, comments, "An interesting conclusion of the study is that in most cases the total capital investment is less when coal cleaning is used than when it is not. The capital investment required for coal cleaning can be more than offset by power plant savings. These savings result because clean coal generally requires a smaller boiler and reduced flue gas desulfurization."

The capital investment required even for a sophisticated cleaning plant is less than $50/kW, whereas that required for a new power plant is more than $800/kW.

The study showed that most new power plants could benefit from coal cleaning. This is particularly true if plant availability is improved. In fact, for the 1000-MW plants in the study, each 1% gain in availability translated into an estimated savings of at least $1.5 million a year.

Growth in coal use

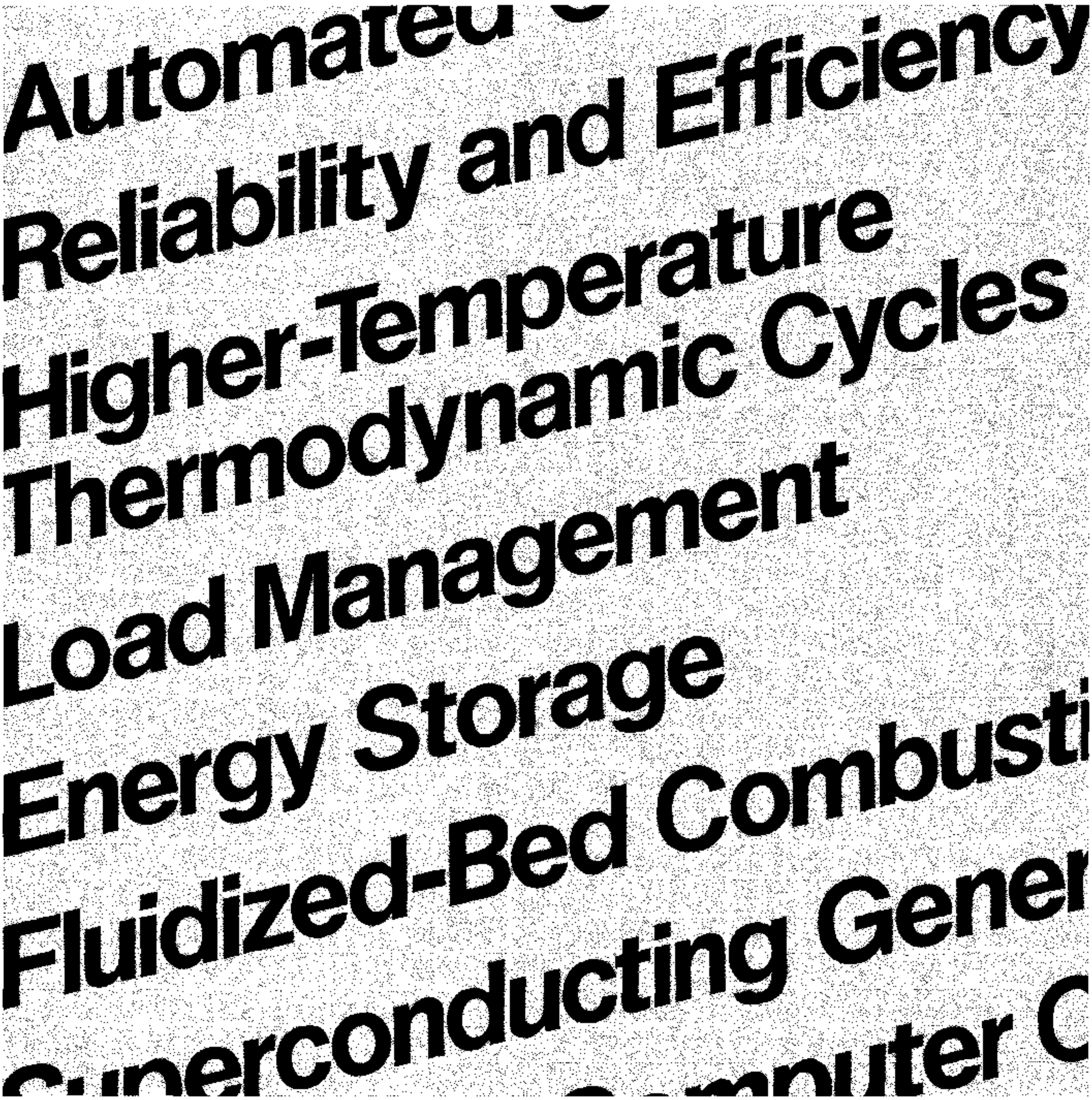
The Coal Cleaning Test Facility, as part of EPRI's Coal Quality Program, is becoming one of the major sources of national near-term R&D in this field, now that DOE's coal-cleaning program is being reduced and directed toward long-term R&D. In the event that the test facility is called upon to undertake even more R&D than was originally planned, it is well able to adapt to this kind of change because of the planned allowance for added systems and the flexibility in equipment combinations.

Considering that by 1995 new growth alone in utility coal consumption will be nearly three times greater than total coal consumption by the industrial sector, the opportunity to boost the heating value of this key fuel and to reduce the wear and tear in plant systems looks more worthwhile every year. Karlson estimates that by 1990 the electric utility industry will be spending about $3 billion per month for coal. "The work of EPRI's Coal Cleaning Test Facility is significant not so much in cleaning coal per se," he says, "but for minimizing electricity generation costs." With the financial curbs now evident in the utility industry, coal cleaning can also go toward maximizing the availability of existing plants and so postpone capital spending for new units. ■

This article was written by Jenny Hopkinson. Technical background information was provided by Frederick Karlson and Douglas Trerice, Coal Combustion Systems Division.

Trends in Electric Power Technologies

Larger power plants, rising fuel costs, and stricter environmental controls tally up to a considerable amount of capital required to fund new plants. R&D is directed at keeping that capital investment as low as possible by operating plants more efficiently and reliably.



Today's new power plants are nothing like the plants of a generation ago, many of which are still operating. Those earlier plants were relatively small and inefficient. Because they burned inexpensive fuels—coal, oil, and gas—plant efficiency was not a major goal. Then electricity networks grew, and the plants had to become larger to support burgeoning electricity demand. Efficiency became important to reduce the cost of the heat-rejection system, particularly the very large condensers. Although these larger plants required large amounts of capital, economies of scale and increased efficiency worked together to reduce the real cost per kilowatt of new power plants.

But events in the past 10 years have combined to send power plants on a different course. The fuels that were once cheap are now costly. Coal, $12 a ton in 1970, nearly doubled in price by 1980 to $23 a ton. Oil, 20¢ a gallon in 1970, almost tripled to 55¢ in 1980. And gas, at 28¢ per 1000 cubic feet in 1970, was more than six times that, $1.80, in 1980. Meanwhile, stricter environmental legislation encumbered new plants with air, water, and land restrictions. Electrostatic precipitators, flue gas desulfurization equipment, and baghouses were needed to keep the air clean. Cooling ponds and towers have materialized where new plants can no longer discharge cooling water into rivers, lakes, and oceans. Disposal regulations for coal ash and desulfurization sludge followed solid-waste disposal legislation. Regional restrictions on land use and siting have made it harder to site plants and even transmission lines.

These changes in power plants have guided changes in electricity R&D. Larger populations dependent on larger plants mean that reliability is of paramount importance. New plants produce 800, 900, 1000 MW; the loss of a large central plant for even a day because of some unforeseen maintenance problem can result in industry shutdowns or can cost hundreds of thousands of dollars for replacement power from neighboring electricity networks. Jumping fuel prices require increases in plant efficiency to pry every possible Btu from costly fuels. And at the same time, environmental protection regulations, land-use restrictions, and the equipment and provisions to comply with them complicate the struggle for higher efficiency.

But perhaps the biggest difference in the new plants is the huge lumps of capital required to build and run them. This capital investment is a direct function of the larger size and greater complexity of the new plants. Today, R&D is directed at keeping that monumental capital investment as low as possible by operating plants as efficiently and reliably as possible.

Today's technology trends

R&D at EPRI illustrates the emphasis on maximizing power plant efficiency and reliability while keeping the lid on capital investment. Consider control of power plants and of transmission and distribution systems. Man-machine studies at EPRI and elsewhere seek to aid operator judgment and minimize human error. In EPRI's Nuclear Power Division, for example, a model of plant operations is being developed that can keep operators continuously informed of in-plant events. The disturbance analysis and surveillance system (DASS) will provide on-the-spot assessments of plant status by using operations information coupled with a conceptual model of key plant subsystems. Rather than keeping mental track of banks of meters and dials, the operators will be able to observe vital system events on an easy-to-comprehend screen. Control is shifting from the human operators who have always manned the controls to automated computer control, with humans as overseers of the system.

Higher-temperature thermodynamic cycles are also being explored to increase fuel conversion efficiencies. These cycles were historically limited by the unavailability or unapproachable cost of the materials required. Today, however, high-temperature gas topping cycles are being developed. Although such topping cycles appear expensive for current use, the economic value of increased conversion efficiencies may soon justify them.

An example is work on experimental gas turbine blades in EPRI's Advanced Power Systems Division. Corrosion, erosion, and deposition are major problems at current turbine metal temperatures of 1500–1700°F (815–927°C) and gas inlet turbine temperatures of 2000°F (1093°C). These problems could be severely aggravated when new designs raise gas temperatures to 2300°F (1260°C). Advanced cooling techniques to keep the metal temperatures down in the 1400–1600°F (760–871°C) range without using large amounts of compressor discharge air might be one solution. EPRI is studying new cooling schemes for turbine blades that include new materials and fabrication techniques.

Higher efficiency and lower capital cost are also the moving force behind generator research. The largest state-of-the-art electric generators are now approaching the limits of mechanical strength, and near-term cost and reliability problems are surfacing. These generators are now so large that they must be disassembled for transport, then reassembled at the power plant construction site. The increased risk of errors in reassembling the generators could result in reduced reliability.

Superconducting generators may be an alternative. The superconducting generator coils are cooled at near absolute zero, a condition in which electric resistance in the generator's wire coils virtually disappears. It has been estimated that the new design will cut the generator's electricity losses almost in half, boosting its conversion efficiency close to 99%. Because they are more efficient, these generators would also be smaller than their conventional counterparts.

EPRI's Electrical Systems Division and Westinghouse Electric Corp. are cosponsoring the design, construction, and testing of a 270-MW liquid-helium-cooled superconducting generator. Further ap-

Historically, higher-temperature thermodynamic cycles have been limited by the unavailability or unapproachable cost of materials for such cycles, yet the economic value of increased fuel conversion efficiencies may soon justify them.

plications of superconductivity have yet to be fully explored, including the concept of a superconducting transmission line that could transfer very large quantities of electric power with extremely low losses.

The need to meet environmental regulations and produce electricity more efficiently is also behind the development of atmospheric fluidized-bed combustion (AFBC), an area of active EPRI, TVA, and DOE research. The AFBC boiler contains a bed of coal and limestone fluidized by incoming air. Because some of the boiler tubing is directly submerged in the burning coal and heated limestone, heat transfer in the AFBC boiler is vastly more efficient than in a conventional boiler. This improved efficiency means less boiler tubing surface is necessary to generate the same amount of steam as a conventional boiler, so capital costs are reduced. And because of improved efficiency, the boiler can be operated at comparatively low temperatures, thereby eliminating the formation of slag and suppressing the formation of nitrogen oxides. The limestone in the boiler feed reacts with SO_2, trapping it in a dry calcium-sulfate waste product.

Recent AFBC research focused on EPRI's 6-by-6-ft, 2-MW (e) development facility at Babcock & Wilcox Co.'s Alliance (Ohio) Research Center, where combustion efficiencies of more than 99% have been achieved. This year, construction was completed at TVA's 20-MW (e) AFBC prototype. TVA and EPRI will begin full testing of the prototype this fall. A 100–200-MW (e) utility AFBC demonstration is planned for later this decade.

Nuclear power plants are also on the list for efficiency, reliability, and cost improvements. They have the highest power density of any large energy source, with all the attendant problems of heat transfer to conventional turbine cycles. Every type of cooling—gas, water, steam, and liquid metal—has been used in nuclear plants. Because of the high heat transfer rates, reactor control and instabilities have dominated safety studies. The integrity of fuel assemblies and core structures is also an important area of continuing study.

EPRI is actively looking into all these areas, with promising results. For example, pellet-cladding interaction (PCI) in nuclear fuel rods can cause rod failures. To avoid this, utilities operate their nuclear reactors within conservative limits, resulting in a significant capacity loss. Laboratory and test reactor experiments, examination of irradiated fuel rods from commercial reactors, and model development sponsored by EPRI and others have provided a better understanding of the PCI phenomenon. This knowledge is being used to develop PCI-resistant fuel rods.

Future technology trends

While research goes on, future technology trends are in the making. Fossil fuel costs are likely to continue to rise because of the long-range economics of increasing scarcity. As low-cost fuel sources become depleted, higher-cost sources are tapped. This will sustain the shift away from scarce fuels. In the United States, the trend is toward coal and nuclear plants. In most other countries, the trend is primarily to nuclear. Both coal and nuclear plants are extremely capital-intensive, so present-day research trends toward lower costs, higher efficiency, and greater reliability can be expected to persist.

Now and in the future, the efficient use of all energy resources requires optimization of the total utility system. This includes not only generation, transmission, and distribution but also customer use. Load management is increasingly being employed to shift peak electricity demand to off-peak periods or to reduce peak demand growth. According to a recent EPRI–DOE survey, over 100 utilities are currently involved in a range of load management programs. In some programs, the utility directly controls such end uses as water heating or air conditioning. In other programs, customers may alter their demand after considering utility rate incentives that reward electricity use at off-peak periods. With either approach, the objective is to adjust the timing of customer demand to minimize the total cost of electricity.

EPRI's Energy Analysis and Environment Division is now studying whether the load management experiences of one utility can be extrapolated for use by another utility, thus reducing the funds required for experimental load management programs. The EAE Division is also developing data and models to estimate the impact and cost-effectiveness of load management. Elsewhere at EPRI, the Electrical Systems Division is researching time-of-use meters and other load management hardware, and the Energy Management and Utilization Division is researching customer-side load management hardware, including heat and cool storage devices and logic controls for such loads as lighting, air conditioning, and electric heating.

Large central power plants will continue to be built, but there will also be opportunities for smaller, decentralized plants. The future generation mix will be one of centralized and decentralized power plants, arranged to fit demographic load distributions, reliability considerations, and fuel availability. Fuel cell power plants, for example, may permit an efficient use of existing natural gas systems to provide decentralized power for peaking or emergency use. Other relatively small, dispersed sources of electricity will include battery energy storage and cogeneration.

EPRI's EMU Division is carefully examining the prospects of the new dispersed technologies. Control and checkout tests are under way in Manhattan at a 4.5-MW fuel cell demonstration. This demonstration, of which EPRI is a major sponsor, is being conducted on Consolidated Edison Co. of New York, Inc.'s grid, and operation should begin later this year. Meanwhile, acceptance tests have been completed at the Battery Energy Storage Test (BEST) Facility in New Jersey. This facility was organized under the joint sponsorship of EPRI, DOE, and Public Service Electric and Gas Co., with PSE&G acting as prime contractor and host for the program. Evaluation of advanced batteries for utility energy storage will be ready to begin when a 500-kWh zinc chloride unit, first in a planned 10-year test series of candidate units, is delivered later this year.

So, the optimum of technology, reliability, and scale is shifting within the utility industry. Bigger power plants are not always better. Efficiency, reliability, and cost-effectiveness are essential. High technology will pace the achievement of these goals. Besides the conventional engineering necessary for the construction of power plants, the industry now employs specialties that formerly had little to do with power plants: material sciences; electrochemistry and corrosion; nondestructive testing; surface chemistry and physics; system dynamics and control; man-machine interactions; energy economics; reliability engineering; risk analysis; environmental sciences; physiologic toxicity and public health; meteorology; seismology; and still others. Although the recent decline in the national economic growth and some overly optimistic utility expansion commitments of a decade ago have combined to produce an excess of generating capacity, this excess will quickly disappear when the economy returns to a normal growth rate. The power plants of the future will offer an increasingly challenging frontier for technology. ■

This article was adapted by Nadine Lihach from a speech delivered by Dr. Chauncey Starr, vice chairman and founding president of EPRI, at the Engineering Educators Banquet of the Edison Electric Institute, June 22, 1981, in Los Angeles, California.

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DOE Takes the Lead in CO_2 Research

Scientists have been considering the long-term implications of increased amounts of carbon dioxide in the atmosphere for over 80 years, but despite the millions of research dollars spent, very little is known. With DOE as the lead agency, a comprehensive federal CO_2 program is responding to the need for continued, cooperative research.

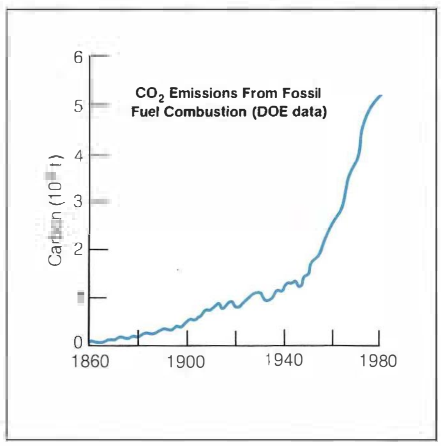
Carbon dioxide is a gas created primarily from the burning of fossil fuels—coal, gas, and petroleum—and the oxidation and decay process of trees, plants, and other living matter. The molecules of CO_2 in the atmosphere act as a one-way filter, permitting sunlight to pass through but stopping the longer wavelength infrared radiation into which sunlight is converted as it strikes Earth. This process is similar to that which occurs in a greenhouse, where the glass allows the light to penetrate but traps the resultant heat inside. The heating process that results from the CO_2 in the atmosphere is thus often called the greenhouse effect.

The extent to which this greenhouse effect will affect the climate is uncertain. Some projections, which assume a doubling of current CO_2 levels, suggest that worldwide temperatures could increase in the range of 1.5–4.5°C within the next 50–75 years.

Disparate theories held by many of the most renowned scientists center on whether such a warming would have an unfavorable or favorable impact on world economy. For example, some scientists claim that the resultant climate and rainfall alterations would be catastrophic, causing the west Antarctic ice sheet to melt, coastal areas to be inundated, and agricultural regions to shift. Other scientists see benefits from CO_2 increases, including reductions in heating requirements, lengthening of growing seasons, and creation of highly productive regions from desert areas.

Measurements indicate that CO_2 levels in the atmosphere have risen from 315 to 340 parts per million over the past 23 years, primarily as a result of increased fossil fuel use. DOE has analyzed data on fossil fuel consumption that show 1981 releases of 5.3 gigatons of carbon to the atmosphere as CO_2. DOE also reported that the growth rate of carbon emissions, which averaged over 4.5% per year throughout the third quarter of the century, has dropped to less than 2.5% per year since 1973. However, most earlier studies of the CO_2 issue have assumed future growth rates closer to the earlier, higher number.

Why this change in the growth rate of carbon emissions, how any increase in CO_2 in the atmosphere will affect climate and rainfall patterns, and what social,



economic, and environmental impacts will result remain to be understood. In response to the need for continued research and hoping to minimize these uncertainties, the federal government is proceeding with a cooperative effort.

Federal Initiatives

The Interagency Committee on Carbon Dioxide and Climate, with DOE as the lead agency, is carrying out a federal research effort to better understand CO_2 effects. This committee is a subcommittee of the National Climate Program Office of the Department of Commerce, which coordinates climate program and research committees throughout the government.

According to Frederick Koomanoff, director of the Carbon Dioxide Research Division at DOE, by coordinating federal CO_2 work, productivity is increased and duplication of research efforts is reduced. "We are taking advantage of each program's strengths and skills. For example, the National Oceanographic and Atmospheric Administration maintains the world's sampling network. We, at DOE, are gathering information needed for fossil fuel emissions models. The Department of Agriculture is examining the effects of CO_2 on vegetation and conducting physiology and photosynthesis studies of plants. We are able to move right in and work with them, and in effect, we complement each other."

Other organizations participating in the interagency group include the U.S. Geological Survey, the National Bureau of Standards, the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation (NSF), and the Department of State.

"We are not in a position to recommend any energy policy decisions regarding the CO_2 issue at this point," Koomanoff explains. "We do, however,

Koomanoff

have time to conduct the research that will lead to intelligent decisions based on scientific knowledge and facts and not just on emotions and reactions. We are working with the international community so we can learn and grow together." Internationally, active U.S. cooperation exists with Japan, Canada, and the European Community.

Efforts to evaluate CO_2 research are also in progress. For example, the Office of Science and Technology Policy (OSTP), as mandated in the Energy Security Act, is assessing the quality and efficiency of current federal CO_2 research efforts. With NSF and DOE funds, OSTP requested the National Academy of Sciences (NAS) to perform the assessment for them. William Nierenberg, director of the Scripps Institute of Oceanography and chairman of the NAS study, feels that the agencies are doing a good job of communicating with one another and coordinating their efforts. "None of the agencies has tried to influence our results in any way. They have been extremely cooperative and forthcoming with information." NAS will report to Congress on all essential aspects of CO_2 research, including the adequacy of federal efforts and what is under way on an international level, within the next year and a half.

DOE's CO_2 program is the largest of the federal efforts. In FY82, the program was appropriated $12 million; $8 million has been proposed for FY83. DOE's program is geared toward achieving a good quantitative data base to assist in effective energy policy decision making. Koomanoff remarks, "Right now, the implication of increased atmospheric CO_2 is a perceived problem. Our goal is to obtain the scientific data to determine if it is indeed a real problem." By concentrating on the global carbon cycle, climate modeling, vegetation effects, first detection, and second-order effects, DOE hopes to project future atmospheric CO_2 levels and assess their direct and indirect impact on climate and agricultural productivity.

Initially, Koomanoff's staff will produce a series of state-of-the-art reports for each of these areas, after which the results will be synthesized into a statement-of-findings report, which will be released in early 1985. "The assessment report will not be definitive," Koomanoff explains. "It will document the knowns, the unknowns, the uncertainties, and any additional research requirements." The program will focus primarily on three specific areas: the global carbon cycle, the effects of CO_2 on climate, and the effects of CO_2 on vegetation.

The Carbon Cycle

With CO_2 being continuously dissolved in the ocean and also being utilized in the terrestrial biosphere, there is a constant exchange of the CO_2 in the atmosphere. Uncertainties prevail in understanding these exchanges, and more specifically, in identifying the sources and sinks of carbon dioxide—where CO_2 comes from and where it goes. These uncertainties make predictions of future atmospheric CO_2 concentrations difficult.

Although forests and oceans (from surface levels to the deep seas) act as organic receptacles, or sinks, for CO_2, it is not certain how much and how quickly the absorption takes place, nor is it possible to make accurate estimates of future deforestation trends (e.g., forest clearing, burning, abandonment of farmland). DOE is working with NSF and leading oceanographic groups, such as Scripps and LaMont-Doherty Geological Observatory, to learn more about the oceans, including the mixing process that occurs between surface and deep sea levels.

Once there are scientifically accepted data regarding how much CO_2 ends up in the atmosphere and how much is absorbed by the oceans, the effect on climate can be simulated by computer models.

Climate Modeling

The accurate prediction of regional and worldwide fluctuations in temperature and precipitation is a challenging task. Identifying which climate changes are directly attributable to CO_2 effects and which are caused by other factors, such as atmospheric debris from volcanic eruptions, changes in solar radiation, and other atmospheric gases like the Freons, ammonia, and nitrous oxide, is a difficult endeavor.

Koomanoff stresses the need to "find a signal in the atmosphere to directly link an increase in CO_2 to climate change. This is mandatory if we are going to be able to make future policy decisions. We already know that when CO_2 is increased, the temperature rises. However, we don't know the magnitude, the regionality, or the seasonality of the temperature change and other climate variables. Our climate models are too global."

Koomanoff notes that it may never be possible to attribute a climate change directly to an increase in atmospheric CO_2. Models are currently being used to predict the temperature changes that would be caused by the 14% increase in CO_2 since the turn of the century; however, the natural variability over the 100-year record of the global average temperature is about $\pm 0.4\,^{\circ}C$, which is greater than that expected from the 14% increase in CO_2.

Nevertheless, it is important to explore methods for detecting the small changes that the models predict and attempt to isolate those predicted changes associated with CO_2 and those that may be caused by other factors. Current research aimed at detecting climate change will enable scientists to test atmospheric models by comparing the predicted effects with those already measured.

To identify and quantify first- and second-order climatic effects of increased CO_2 concentrations, the climate modeling program must implement several types of models. These models vary in complexity from one-dimensional, involving only vertical atmospheric processes, to three-dimensional, which take into consideration clouds, ocean circulation, water vapor, and other factors. Although a computer run involving a one-dimensional model will take only seconds, the three-dimensional, or general circulation, model can take up to 100 hours to run. These three-dimensional models are still not complete because of the complex interaction between the components of climate models, including atmospheric composition, land-sea distributions, seasonal variations, ocean heat capacity, and cloud processes. If climate is affected, so also are temperature, cloudiness, and precipitation, and whether the correspondence is positive or negative, there will be an effect on vegetation.

Vegetation Effects

In the process of photosynthesis, plants convert CO_2 from the atmosphere into organic material. Increasing the amount of CO_2 in the atmosphere, therefore, may increase the growth of plants. Research is under way to provide a basis for predicting vegetation response to increased atmospheric levels of CO_2. By examining the photosynthesis, physiology, and water use of plants, such effects can be measured. For example, much is already known about the way in which plants absorb CO_2 and (through transpiration) release water. What is not fully understood, however, is the CO_2-water relationship in plants and whether that relationship will be positive.

When more is known about vegetation processes, detection of indirect, or second-order, effects will be facilitated. Possible CO_2-climate–induced effects include ocean temperature and circulation changes, which might, for example, cause changes in the fishing industry. "When everything is put together, we'll know what is required to get the answers. Our job is to increase knowledge, which in turn should decrease uncertainty. Options can then be posed, and we can move forward," Koomanoff adds.

Integral to this cooperative CO_2 research effort are the ensuing spinoffs. "Through better understanding of the oceans, we will know more about fish and mariculture, for example. By understanding more about CO_2 fertilization, we'll know more about the physiology of plants and how to produce more per acre. Anything we do to improve climate models will be beneficial. Therefore, no matter what, there will be positive payoffs from this extensive research." ■

This article was written by Ellie Hollander, Washington Office. Technical background information was provided by Michael Tinkleman, Washington representative, Energy Analysis and Environment Division.

Compressed-Air Power

Illinois power cooperative
pioneers compressed-air energy storage (CAES)
in the United States.

Preliminary construction has begun on the nation's first CAES plant, a 220-MW, 60-cycle plant being built for Soyland Power Cooperative in Pike County, west of Springfield, Illinois. The plant, expected to be on-line in June 1986, will be the second commercial CAES plant in the world. The first such plant was the 290-MW, 50-cycle Huntorf facility, which has been operated successfully by remote control, unattended, in the Federal Republic of Germany since December 1978.

Robert B. Schainker, EPRI project manager for thermal and mechanical energy storage, said the Soyland plant will use an underground cavern carved out of dolomite rock to store the compressed air. The cavern will be designed to store enough air at a pressure of 55 atm (5.6 MPa) to generate 220 MW of power for up to 11 hours.

Schainker said off-peak power will be used to pump the air into the cavern at night. As the air enters the cavern it will displace water, forcing the water up a shaft to a surface reservoir. During peak daytime periods, the air will be released into a turbine expansion generator to produce power; gravity will then force the water back into the cavern, where it will maintain the air at constant pressure.

A synchronous motor generator set will function as a motor to drive the compressors at night and will be driven by the turbine expander during the day to produce electric power. A recuperator will recover waste heat from the turbine expander to reduce the plant's fuel requirement. Each of these plant components will be off the shelf; components such as these have been used by the utility industry in a number of different applications.

The Soyland plant, which will cost an estimated $156 million in 1982 dollars, will provide generation to 15 electric cooperatives (supplying power to about 40% of the land area in Illinois) and will occupy a 100-acre (405 km^2) site. Brown Boveri Corp., whose German subsidiary built the Huntorf plant, is providing the turbo machinery. The balance of the surface machinery will be designed by Gibbs & Hill, Inc., under subcontract to Brown Boveri. Reynolds, Smith & Hills, Inc. (RS&H), architects and engineers, will supervise the effort for Soyland. The cavern will be constructed by the Cementation Co. of America, with subcontracts to Acres-American and Golder Associates.

RS&H will also serve as the engineer of record and document the design, excavation, construction, and first year of operation of the plant for the benefit of the rest of the U.S. electric industry.

Since 1977 EPRI has conducted a number of detailed engineering studies on CAES, along with DOE and individual utilities. Projects with Potomac Electric Power Co. (Pepco), Middle South Services, Inc., and Public Service Co. of Indiana have investigated the use of hard-rock caverns, salt domes, and aquifer reservoirs for containing compressed air.

The Pepco report was applicable to the Soyland project and is being used by Soyland's project management. In its study, Pepco determined that a CAES plant similar in size to Soyland's would save Pepco and its customers 400,000 barrels of oil a year and $500 million (in 1982 dollars) over a 30-year lifetime for the plant.

Schainker said two-thirds of the U.S. land area has geologic structures (salt domes, hard rock, or aquifers) suitable for CAES. He estimates that the generating potential for CAES in the United States over the next 20 years will be between 1000 and 10,000 MW.

Four Appointed to EPRI Board

Three electric utility executives were named and a fourth reappointed to positions on EPRI's Board of Directors at its recent annual meeting.

Robert N. Cleveland, president of Buckeye Power, Inc., in Columbus, Ohio; Charles J. Dougherty, chairman and chief executive officer of Union Electric Co. in St. Louis, Missouri; and William B. Reed, president of Southern Company Services, Inc. (SCS), in Birmingham, Alabama, were named to four-year terms on the Board. A. J. Pfister, general manager of Salt River Project in Phoenix, Arizona, was appointed to a second four-year term and named vice chairman of the 15-member EPRI Board.


Cleveland


Dougherty


Reed


Pfister

Cleveland, who will represent rural electric cooperative utilities, has a long history of service to rural electricity programs around the country. In addition to his current position with Buckeye, which he accepted in 1977, he is president of the Ohio Rural Electric Cooperatives, Inc. Both groups are service organizations for Ohio's rural cooperatives. Before assuming his current roles, Cleveland headed similar organizations in Kentucky and Colorado.

Both Dougherty and Reed will represent investor-owned utilities. An employee of Union Electric for more than 40 years, Dougherty was elected president of the company in 1966 and chief executive officer in 1968. In 1980, he was given the additional duties of chairman. Beyond his work with Union Electric, Dougherty has been active in several utility organizations. He currently serves on the boards of the Edison Electric Institute, the Association of Edison Illuminating Companies, and the Atomic Industrial Forum.

Reed joined SCS in 1969, following a long career with General Electric Co. In 1977 he became president of the firm, which provides technical and other specialized services to The Southern Company and its four electric utility subsidiaries in the Southeast. In his position with SCS, Reed also serves as a vice president and director of The Southern Company. Reed is a director of the Atomic Industrial Forum and the American Nuclear Energy Council and is a member of the American Society of Mechanical Engineers.

Representing public power's interests, Pfister has been a distinguished EPRI board member for the past four years. He joined Salt River Project in 1970, following 11 years as an attorney in private practice. An active member of the Phoenix community, Pfister is associated with a host of civic and professional organizations. He is past president of the American Public Power Association and currently serves on the boards of the Western States Water and Power Consumers Conference and the Institute of Nuclear Power Operations.

Board Adjusts 1982 R&D Budget

At its regular April meeting the EPRI Board of Directors approved a $10 million adjustment in the 1982 R&D budget, bringing it to $260 million. The move was related primarily to delays on several major projects—some work will be accomplished in 1982 rather than in 1981, as originally planned.

Under the revised appropriations budget approved by the Board, adjustments in the 1982 funding of major projects include the Cool Water coal gasification plant, the Exxon Donor Solvent pilot plant, and the superconducting generator. The revised appropriations budget includes other small adjustments in many of the Institute's R&D program budgets. Such adjustments are made each year in April to fine-tune projections of expected R&D expenditures for the rest of the year.

In addition, the Board approved a preliminary 1983 R&D budget figure of $280 million. To support that 1983 budget, member utilities will be asked to contribute 0.26 mills ($0.00026) per kilowatthour of 1981 sales, up from 0.236 mills per kWh. The result will be an overall 1983 budget of $335 million, with $280 million going for contract R&D expenditures, $50 million for in-house research and program management, and $5 million for special projects.

The Board also approved a five-year forecast, which projects that R&D expenditures will rise to $482 million by 1987, with member utilities contributing 0.394 mills per kWh that year.

International Electric Research Exchange

Thirteen senior EPRI staff members represented the United States when delegates from nations participating in the International Electric Research Exchange met in San Francisco in April. Some 40 IERE leaders from 13 countries attended the organization's 12th General Meeting, which was chaired by EPRI President Floyd Culler. Following three days of technical and business sessions, participants traveled to Albuquerque, New Mexico, to tour a Public Service Co. of New Mexico load management research facility and a University of New Mexico solar power installation. They also visited EPRI's Arapahoe test facility in Denver, Colorado.

Six More Utilities Become International Sponsors of NSAC

Electric utilities in Belgium, Brazil, Federal Republic of Germany, Great Britain, Mexico, and Spain have become international sponsors of the Nuclear Safety Analysis Center operated by EPRI. They bring to 12 the number of countries in the growing group of NSAC sponsors who are working together to ensure the highest standards of nuclear power safety. Electric utilities in France, Sweden, Japan, Taiwan, Canada, and Italy (in chronological order of membership) have already become NSAC sponsors.

The six new member utilities represent 27 additional operating nuclear power units, plus 26 units under construction for completion in the 1980s. These operating nuclear plants are now brought into instant communication with 77 operating nuclear units in the United States and with 78 in the first six international NSAC sponsors.

The new sponsoring utilities are the Electronucléaire group of Belgium; Furnas Centrais Electricas SA of Brazil; the Rheinisch-Westfäliches Elektrizitätswerk Ag of the Federal Republic of Germany; the Central Electricity Generating Board, which serves England and Wales; the Comisión Federal de Electricidad of Mexico; and Tecnatom SA of Spain, representing seven Spanish electric utilities.

The six new member utilities' 27 operating nuclear plants include 3 in Belgium, 1 in Brazil, 2 in Germany, 18 in Great Britain, and 3 in Spain. Of the plants under construction, 4 are in Belgium, to be in service by 1984; 2 in Brazil; 1 in Germany; 8 in Great Britain, 6 of which are to be operating commercially by 1989; 2 in Mexico; and 9 in Spain.

The utilities in all 12 countries mentioned have also become sponsors of the Institute of Nuclear Power Operations. INPO's principal objective is to improve and set standards for excellence in the operation of nuclear power plants. It establishes guidelines for training nuclear plant personnel, makes annual inspections of the operating performance at each U.S. nuclear power plant, and investigates plant-specific problem areas. NSAC studies generic safety questions (i.e., those common to a type or class); works on improvements in details of design, as well as on new safety devices; and makes recommendations directed toward ensuring the highest attainable level of nuclear safety.

EPRI Active at APC

EPRI was an active participant in the 44th Annual Meeting of the American Power Conference held in Chicago, April 26–28, 1982. Communications and Member Services representatives staffed EPRI's exhibit booth, while several members of the technical staffs either participated in or chaired various conference sessions. Selected demonstration models and photographs, representative of EPRI technology development and application, were displayed at the exhibit booth.

The Nuclear Power Division provided a model of Minac, a miniature linear accelerator, which was developed at EPRI's Nondestructive Evaluation Center in Charlotte, North Carolina, for radiographic inspection of reactor coolant pump welding. A model of the 100-MW Cool Water coal gasification–combined-cycle plant, now under construction in Daggett, California, was supplied by the Advanced Power Systems Division. Models of the Coal Combustion Systems Division's Arapahoe Emissions Control and Test Facility in Colorado, and the Energy Management and Utilization Division's compressed-air energy storage facility, which uses salt domes to store off-peak energy, were displayed. Samples of a metal oxide surge arrester were on hand from the Electrical Systems Division.

EPRI's technical division directors provided the APC registrants with a three-hour briefing on the Institute's major research results. Richard Balzhiser, vice president, Research and Development Group, accompanied by Richard Zeren, director, Planning and Evaluation Division, introduced the session. With federal emphasis shifting toward long-term energy R&D, Balzhiser emphasized the increasing importance of EPRI's near-term research results and their application. Division directors René Malès, Energy Analysis and Environment; Kurt Yeager, Coal Combustion Systems; John Taylor, Nuclear Power; Dwain Spencer, Advanced Power Systems; John Dougherty, Electrical Systems; and Fritz Kalhammer, Energy Management and Utilization, highlighted progress on significant projects that are under way or that have already yielded results.

CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

JULY

7–9
Workshop: Steam Turbine Blade Reliability
Boston, Massachusetts
Contact: John Parkes (415) 855-2451

14–16
Seminar: Current Electrostatic Precipitator Technology
Nashville, Tennessee
Contact: Walter Piullet (415) 855-2470

15–16
Torsional Fatigue Strength of Large Turbine Generator Shafts
Denver, Colorado
Contact: Dharmendra Sharma (415) 855-2302

20–22
Seminar: Human Factors Design Guidelines
Alexandria, Virginia
Contact: Howard Parris (415) 855-2776

28–30
Environmental Control Technology for Coal Gasification Processes
Palo Alto, California
Contact: William Reveal (415) 855-2815

28–30
Seminar: EPRI Cogeneration Model
Oakland, California
Contact: Larry Williams (415) 855-2415
David Hu (415) 855-2420

AUGUST

2–6
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

9–11
Conference: Power Plant Availability
Dearborn, Michigan
Contact: David Poole (415) 855-2458

9–13
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

16–20
Foundation Design of Transmission Line Structures
Denver, Colorado
Contact: Phillip Landers (415) 855-2307

25–27
Incipient Failure Detection for Fossil Plant Components
Hartford, Connecticut
Contact: Anthony Armor (415) 855-2961

25–27
Solar and Wind Power, 1982 Status and Outlook
Providence, Rhode Island
Contact: Edgar A. DeMeo (415) 855-2159

SEPTEMBER

8–10
Workshop: Steam Turbine Bearings and Rotor Dynamics
Detroit, Michigan
Contact: Tom McCloskey (415) 855-2655

20–22
International Conference: Compressed-Air Energy Storage and Underground Pumped Hydro
San Francisco, California
Contact: Robert Schainker (415) 855-2549

21–22
Seminar: Cathodic Protection of Bare Copper Neutral Conductors on URD Cables
Kansas City, Missouri
Contact: Thomas Kendrew (415) 855-2317

OCTOBER

7–8
Cooling-Tower Plume Prediction
Chicago, Illinois
Contact: John Bartz (415) 855-2851

13–14
Seminar: Cathodic Protection of Bare Copper Neutral Conductors on URD Cables
Arlington, Virginia
Contact: Thomas Kendrew (415) 855-2317

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

TWO-STAGE COAL LIQUEFACTION

A major emphasis of EPRI's Clean Liquid and Solid Fuels Program is the development of two-stage liquefaction (TSL) technology, which is believed to have the potential to substantially reduce the cost of synthetic fuels from coal. In the TSL process, coal is liquefied in two reaction vessels, a thermal reactor and a catalytic reactor. In contrast, the H-Coal and Exxon Donor Solvent processes each use only one liquefaction reactor. By exploiting the advantages of both types of reactor and by synergistically integrating the two, TSL promises high yields of fuel oils from coal with a concomitantly low consumption of hydrogen.

TSL's potential for reducing hydrogen consumption per unit of fuel oil product is important because a large part of the capital investment in a coal liquefaction plant, as well as a large part of the operating budget, goes for the production of hydrogen. Thus any reduction in hydrogen consumption for a unit of product would greatly affect the cost of the product. It is hoped that the reduced use of hydrogen in the TSL process will make up for the added costs associated with the increased complexity of a two-reactor system. Other significant benefits of the TSL process are improved operability, improved recycle solvent balance, improved catalyst life, and improved product slate flexibility.

These benefits promise to make the TSL process extremely versatile. By varying the operating conditions of either or both reactors, it is possible to achieve a range of products from distillate to residual fuel oils in practically any combination. Questions still remain about how the reactors should be integrated. Obviously, the method of integration will affect the chemistry and thermodynamics of the process. More experimentation is needed to conclusively define the most efficient scheme.

Toward that end Kerr-McGee Corp., under a jointly funded contract with EPRI (RP1715), has completed the construction of a totally integrated TSL bench-scale unit at its Cimarron, Oklahoma, site. This bench unit will be operated in support of EPRI's 6-t/d pilot plant, the Wilsonville Coal Liquefaction Development Facility, which is located adjacent to Alabama Power Co.'s Gaston generating station. Most of the progress reported in this article has resulted from work at the Wilsonville facility. The Wilsonville project is cosponsored by EPRI and DOE and managed by Southern Company Services, Inc.; Catalytic, Inc., operates the facility.

All of the pilot plant operations thus far have used the simplest form of TSL, the so-called decoupled mode. In this mode the two liquefaction reactors act independently; the residual product of the first stage, solvent-refined coal (SRC), is upgraded in the second reactor, a catalytic hydrotreater. This configuration is well suited to producing either a very low sulfur solid product similar to SRC or a synthetic No. 6 fuel oil. The operations to date have used Kentucky No. 9 and Illinois No. 6 coals as feedstocks.

A previous status report (*EPRI Journal*, November 1981, p. 38) described the option of operating the SRC reactor, which is the first stage in TSL, at temperatures lower than traditionally used. The result was a more efficient operation, without undesirable side reactions that produce gaseous instead of liquid products. This is significant because lower production of gas (a less valuable product) results in lower hydrogen consumption and presumably a lower cost for producing synthetic fuels. Pilot plant runs have now been completed to compare high- and low-temperature reaction conditions for the first stage of the TSL process. Various hydrotreater temperatures have also been tested for each first-stage condition.

The Wilsonville results on TSL have been encouraging. Previous small-scale tests, which involved hydrotreating samples of SRC produced at the pilot plant, had left some doubt about whether hydrotreating could convert SRC into upgraded products without catalyst deactivation and concomitant process performance deterioration. The pilot plant operations have demonstrated the following.

- SRC can be readily and selectively desulfurized in the hydrotreater to produce a low-sulfur (<0.3%) residual fuel that, like the parent SRC, is solid at room temperature.
- By operating the hydrotreater at somewhat more severe conditions, a low-sulfur synthetic No. 6 fuel oil can be produced in quite high yields. (Over 60 wt% of the moisture- and ash-free coal is converted to low-sulfur fuel oil.) Hydrogen consumption is quite low relative to yields. Table 1 shows the composition of a typical TSL fuel oil.

Table 1
SYNTHETIC FUEL OIL PROPERTIES

Flash point (°F; °C)	340 (171)
Pour point (°F; °C)	42 (5.6)
Heat of combustion (Btu/lb)	17,081
Constituents (wt%)	
Carbon	86.8
Hydrogen	8.4
Nitrogen	1.1
Sulfur	0.3
Ash	0.01
Viscosity (Pa·s)	
At 122°F (50°C)	0.790
At 230°F (110°C)	0.024

□ Using the low-temperature first-stage option and a similar hydrotreater temperature appears to greatly reduce the problem of catalyst deactivation.

Even under ostensibly similar operating conditions, the pilot plant results have exceeded the laboratory results. This is probably because the laboratory feed deteriorated to a greater degree on reconstitution and storage. At the pilot plant, fresh feeds are used and storage times are minimized. *Program Manager: Howard Lebowitz; Project Managers: Conrad Kulik and William Weber*

COPRODUCTION OF METHANOL AND ELECTRICITY

One way to ensure the availability of liquid fuel to meet an electric utility system's requirements is to coproduce methanol and electricity in a coal gasification–combined-cycle power plant. Methanol (CH_3OH) *is produced from hydrogen* (H_2) *and carbon monoxide* (CO) *by the following reaction:* $2H_2 + CO = CH_3OH$. *It can also be produced from hydrogen and carbon dioxide* (CO_2), *as follows:* $3H_2 + CO_2 = CH_3OH + H_2O$. *The gasification of coal to produce a fuel gas for firing in a combined-cycle power plant yields a gas whose major components are* H_2 *and* CO; CO_2 *is a minor component. Thus the potential for coproducing electricity and methanol in the same facility is apparent. This report reviews methanol synthesis methods and describes work sponsored by EPRI to determine the feasibility and possible benefits of the coproduction concept.*

Methanol synthesis methods

Figure 1 shows the three methods that can be used to produce methanol: recycle synthesis, shifted once-through synthesis, and unshifted once-through synthesis.

Recycle synthesis (Figure 1a) is the type that would be employed in dedicated methanol plants, with methanol as the only product. For simplicity, the molar ratio of H_2 to CO in the gas from the gasifier is assumed to be 1:1. Actually the ratio is sometimes smaller than this and sometimes greater, depending on the gasifier; however, it is seldom greater than 2:1. Methanol synthesis by only the first reaction noted above—that is, between H_2 and CO—is assumed.

As methanol is the only product of a dedicated facility using recycle synthesis, the feed gas must have a 2:1 molar ratio of H_2 to CO. This is accomplished by first employing a shift converter, in which the following reaction is carried out: $CO + H_2O = H_2 + CO_2$. Then the CO_2 formed in the shift converter is removed from the gas. (In actual practice, a small amount of CO_2 is left in the gas because it enhances the methanol formation

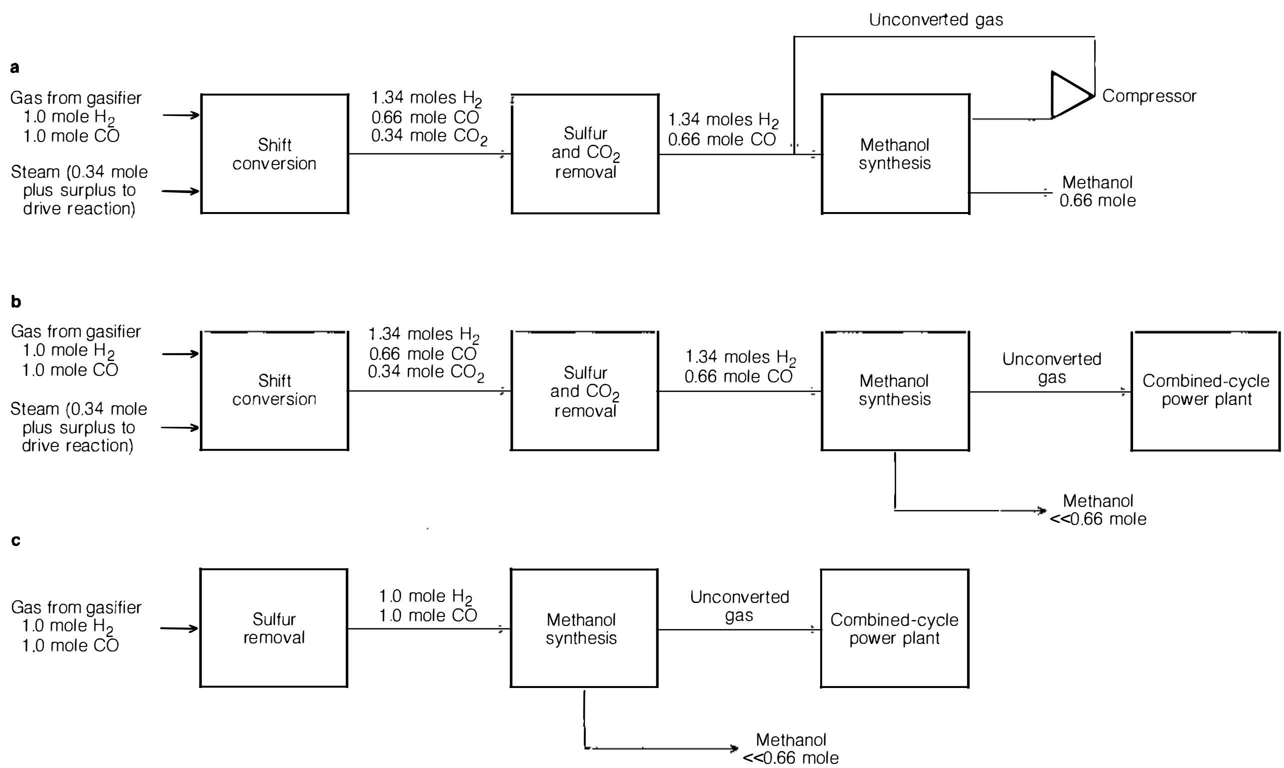


Figure 1 Methanol synthesis configurations. The recycle synthesis method (**a**) is for use in dedicated methanol production plants. Shifted once-through synthesis (**b**) and unshifted once-through synthesis (**c**) are candidates for use in methanol-electricity coproduction facilities. EPRI is exploring the feasibility of the third configuration, which promises the greatest capital and energy savings.

reactions.) As a result of chemical equilibrium limitations, the conversion of H_2 and CO to methanol is low. Because all of the feed gas must be consumed, it is necessary to recycle unconverted gas to the methanol synthesis reactor.

Figure 1b shows shifted once-through synthesis. Molar quantities are assumed to be the same as those given for the recycle method, except that the fraction of gas converted to methanol is substantially lower. This method could be employed in a power plant where there is a desirable use for the unconverted gas—for example, a highly efficient baseload combined-cycle plant. The reduced methanol production is also compatible with this scheme: The methanol could be used in peaking and intermediate-load units, which operate only part-time and thus require reduced quantities of energy.

A comparison of Figures 1a and 1b shows that the shifted once-through synthesis configuration has the potential for capital and energy savings because it eliminates the unconverted gas recycle loop.

Figure 1c shows the ultimate synthesis scheme in terms of capital and energy savings: unshifted once-through synthesis. In this configuration shift conversion, CO_2 removal, and the recycle loop are all eliminated, resulting in a maximum savings of capital and energy. A goal of the Advanced Power Systems Division's R&D program in methanol synthesis is to determine whether this method is feasible.

R&D efforts

In a multiyear program involving both bench-scale and process-development-unit testing, Chem Systems, Inc., explored the once-through synthesis process with unshifted synthesis gas compositions representative of gases that would be produced by various coal gasifiers (RP317). The tests were based on a new methanol reactor concept, an ebullated-bed reactor, in which the synthesis catalyst is fluidized by a circulating inert hydrocarbon liquid (*EPRI Journal,* July/August 1981, p. 44). The circulating liquid also permits the ready removal of exothermic reaction heat, using it to generate steam outside the reactor.

The results of the Chem Systems tests were encouraging in two respects: a suitable inert liquid for fluidizing the bed and removing the heat of reaction was found; and high conversions of unshifted gas to methanol were achieved (i.e., conversions close to chemical equilibrium). The results were discouraging (but only mildly so) in that physical attrition of catalyst particles occurred, and there was a loss of catalyst activity in sustained runs.

After the completion of this work, EPRI retained United Catalysts, Inc., to search for a methanol catalyst formulation that would show both mechanical integrity and activity retention when used in the Chem Systems reactor (RP1656). Several formulations have been tested on small-scale equipment and seem to be promising. One or more of these will be tested in a process development unit and perhaps later in a 5-t/d pilot plant in La Porte, Texas. The pilot plant is a joint effort of EPRI, DOE, Chem Systems, Air Products and Chemicals, Inc., and Fluor Engineers and Constructors, Inc. (RP317-3).

Studies of potential economic benefits

Fluor has prepared a conceptual design and cost estimates for a methanol-electricity coproduction plant based on the unshifted once-through synthesis method (RP239-2). The Texaco gasifier and a conceptual commercial design of the Chem Systems methanol synthesis reactor system were used.

The major finding of this study was that the levelized revenue required for methanol produced by a regulated utility in a coproduction plant would be $4.32 per million Btu (1980 dollars), while the minimum required price of methanol produced in a dedicated coal-to-methanol plant owned by a nonregulated producer would be $7.87 per million (1980 dollars). These results, which are reported in AP-2212, indicate that considerable cost savings and security of liquid fuel supply could be achieved through coproduction plants, provided that EPRI's gasification and methanol R&D programs are successful.

Using the cost data from the Fluor study, Zaininger Engineering Co. has been performing system expansion studies to investigate methanol-electricity coproduction plants as candidates for system additions (TPS81-781). These studies involve 10,000-MW systems expanding at 2% per year. They indicate that the use of methanol-electricity coproduction units as expansion technologies could result in multibillion dollar savings in the present value of fuel costs—savings more than sufficient to offset the increased capital, operating, and maintenance costs of the coproduction units. In some cases the expansion capital requirement could even be reduced below that of more conventional units.

Another study is being conducted to determine the technical and economic feasibility of using a commercially available methanol synthesis reactor (that of Imperial Chemical Industries, Ltd.) in a once-through synthesis configuration. The contractors are Burns and Roe–Humphreys & Glasgow Synthetic Fuels, Inc. (RP2029-1), and General Electric Co. (RP2029-2). *Project Managers: Michael Gluckman, Nandor Hertz, and Bert Louks*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

COAL SLURRIES

*The likelihood of future oil and gas price increases and potential supply problems are strong incentives for converting oil-fired power plants to coal. EPRI has actively investigated the technical and economic feasibility of using coal slurries in power plants currently fired by oil (*EPRI Journal: *April 1981, pp. 6–12; June 1981, p. 34). Studies have been conducted to determine the cost of producing coal-oil mixtures (COMs) in large quantities for utility use and to prepare guidelines for converting power plants to COM use (RP1455). EPRI has also undertaken a project to develop, demonstrate, and commercialize coal-water slurries (CWSs) as a cost-effective oil-replacement fuel for utility boilers (RP1895). Of the types of slurry under consideration, CWSs (i.e., stable, pumpable mixes containing 70 wt% finely ground coal in 30 wt% water) are more promising than COMs (typically 50 wt% coal in 50 wt% No. 6 oil) because they contain no oil and will therefore be cheaper. CWSs also derive all their energy from an abundant domestic fuel. Further, if clean coal is used (i.e., coal containing less than 3% ash) the slagging, fouling, and ash effects on boilers are reduced, and unit derating may be minimized. Slurry production processes are being developed that incorporate a coal-cleaning step. Although COMs have been demonstrated in utility boilers, they can be expected to provide only marginal cost savings to utilities and could easily result in increased power costs. Therefore, future EPRI projects will focus on the rapid development and demonstration of the more promising CWSs.*

Coal-water slurries

In the past year the development of processes for preparation of 70–75 wt% coal in 25–30 wt% water (with less than 1% stabilizing additive) has been scaled up from the laboratory to pilot plants. These pilot plants are typically capable of producing 1–2 t/h of slurry. Even larger plants are being designed or are in the initial stages of construction. The reported production capacity of these small plants ranges from 10,000 t/yr to 250,000 t/yr.

Processes being developed by more than a dozen companies start with finely pulverized coal. Preparation of practical slurries depends not only on the properties of selected coal (such as grindability and surface chemistry) but also on attaining the right particle-size distribution. The size distribution of the pulverized-coal particles must be such that the interstitial spaces between the largest particles are filled with smaller particles. The grinding process must therefore be carefully controlled to achieve a good particle-size fit. Grinding methods based on existing practices in the ceramics, paint, ore-processing, and aerospace industries have been used.

Grinding can be done in a single step or in a two-step process in which a coarse grind and a fine grind are prepared separately and then blended. The single-step grinding process has been used to prepare practical slurries that are 65–75 wt% coal; the average particle diameter is about 50 μm. The two-step process produces an average coarse fraction (about 70 wt% of the coal) particle diameter of 120 μm and a fine fraction (30 wt% of the coal) particle diameter of about 15 μm.

Grinding is done in water (wet grinding) and a coal-cleaning step is part of the process used by several firms. CWSs with low ash and low total sulfur contents (less than 1%) have been prepared by either cleaning the coal or using good coal feedstock. After grinding, the total water content is adjusted to about 25–30% and additives are used to adjust the slurry flow and storage stability properties.

The slurries tend to be thixotropic and have the consistency of latex paint. Slurries are screened to remove oversized particles. Slurries stored in oil storage tanks for prolonged periods require occasional agitation or recycling to rehomogenize them.

Various coal feedstocks, coal treatment processes, grinding methods, and stabilizing processes are being studied. Combustion tests have been performed in small furnaces. Development projects are under way to demonstrate stable combustion in larger boilers.

Atlantic Research Corp. produced about 25 barrels of 67 wt% coal (dry weight) in 32 wt% water (plus 1 wt% additives). Process development studies were completed and combustion tests were conducted in a 1×10^6 Btu/h test furnace (CS-2287). Capital requirements for a production plant producing 6.6×10^6 t/yr of slurry were estimated at $224 million, not including land inventory, working capital, and startup costs. The eventual selling cost for the CWS was estimated at \$3.10/10^6 Btu (RP1895-1).

In a second project the slurry produced by Atlantic Research was fired in a Babcock & Wilcox Co. 4×10^6 Btu/h furnace (RP1895-2). The slurry burned stably under the following conditions.

- The slurry was fired at $3.9–4.4 \times 10^6$ Btu/h.
- Combustion air temperature was 600°F (316°C).
- A commercial oil burner was used.
- A single-fuel hole atomizer sprayer plate was used. The carbon steel sprayer plate eroded severely after six hours of use.
- Slurry viscosity, as measured with a Brookfield RV viscometer, was below 1500 cp (1.5 Pa·s).
- Excess O_2 in the stack was 3.4–5.5%.
- Atomizing air flow was at least 0.05 lb/lb CWS.
- Burner settings were set for maximum swirl and turbulent mixing.
- A swirler-type impeller was used.
- The furnace was preheated to operating temperature.

Work on this project has been completed and the report is available (CS-2288).

B&W is testing eight different slurries prepared by five firms (RP1895-3). Five of the slurries (one from each of the five suppliers) will be made with different coals. Three other slurry samples will be made from clean coal supplied by the EPRI Coal Cleaning Test Facility at Homer City, Pennsylvania. This coal has an ash content of 3.5% and a total sulfur content of 0.8% to yield 1.2 lb $SO_2/10^6$ Btu. B&W is performing bench tests and combustion tests in a 4×10^6 Btu/h furnace. The data will be used to prepare specifications for the testing of slurries and for the procurement of larger quantities for future EPRI demonstrations. The technical work is scheduled for completion in 1982.

Combustion Engineering, Inc., is under contract to develop and demonstrate burners for use with CWSs (RP1895-4). Extensive atomizer tests will be conducted to define droplet ballistics, atomizer location and spray angle, and optimal combustion conditions. Cold flow model tests will be performed, and about 150 t of slurry will be fired in a 50×10^6 Btu/h furnace, using the developed burner nozzle. The slurry for the test is being supplied by Advanced Fuels Technology, a Gulf+Western company. The technical work is scheduled to be completed in 1982.

In addition to the completed and ongoing projects, EPRI is planning to cosponsor a short-term combustion test in a large (200,000 lb/h steam) industrial boiler designed to fire oil. Also scheduled for initiation in 1982 is a project to demonstrate CWS combustion in a small—50 MW (e)—utility boiler and to determine the state of the art of pumps, burners, valves, on-line instrumentation, and other associate equipment. This handling and combustion demonstration is expected to be completed in 1984.

Coal-oil mixtures

EPRI has recently completed an extensive project (RP1455-2) to (1) develop guidelines to aid the utility industry in assessing the technical and economic applicability of COM fuels to existing power plants designed to fire oil, and (2) assess the market potential of a commercial COM commodity through derivation of COM cost. The project was to provide answers to two basic questions. How much would it cost to convert existing oil-design power plants from firing No. 6 oil to firing COM? How much would it cost to prepare and deliver large quantities of COM to utility sites?

The market research, technical analyses, and economic evaluations were performed by Atlantic Richfield Co., Bechtel Group, Inc., and Combustion Engineering. The project endeavored to achieve the following.

- Identify potential utility markets for COM
- Select six plants designed for oil that represented the spectrum of potential candidates for conversion to COM
- Analyze the effects of firing COM on the selected boilers
- Identify boiler and plant modifications to minimize derating
- Calculate the cost of conversion from firing oil to COM
- Establish sensitivity factors
- Prepare guidelines

The product of this study is a short method that most utilities can use to estimate quickly the cost of converting specific power plants from oil to COM. The results are based on a study of six typical boilers ranging in capacity from about 380 MW (e) to 850 MW (e) and representing a variety of boiler configurations and manufacturers. These six boilers are believed to represent over 70% of those designed to fire oil.

Guidelines have been published (CS-2309) and should enable a utility to evaluate the COM conversion option rapidly and with sufficient confidence to decide whether to proceed with a detailed analysis. The report presents complete conversion cost ranges by major modification component, as well as an example calculation that considers site-specific factors. The COM production plant costs will be published separately.

The information provided by the cooperating utilities was used by Combustion Engineering to predict derating in various configurations, sizes, and locations. The predicted derating ranged from 20% to 60%, depending most heavily on the tightness of the boiler design and the quality of coal used (Table 1). The two limiting boiler effects were slagging and tube erosion. The derating level was estimated by assuming that some boiler modifications, such as the installation of wall blowers (deslaggers) and provision for dual-fuel-firing capability, had been made. To complete the study, a number of assumptions had to be made. For example, only two types of coal, one with a high and one with a low ash fusion temperature, were considered; only 50 wt% coal–50 wt% oil COM was considered; and only those boiler modifications that would maintain the ability to switch to 100% oil-firing during peak demand periods were considered. Bechtel estimated the cost for boiler and plant modifications. This cost is site-specific. Again, a number of assumptions were made, including how accessible the plant was to fuel barges and whether a conversion to COM would be considered an existing source, not subject to EPA's New Source Performance Standards of 1979 for SO_2 and NO_X. However, 99% particulate control was provided for regardless of the existing device.

In addition to the capital cost for modifying the power plant, the cost of the COM relative to the cost of oil is pivotal. For this study it was assumed that a large central COM production plant would be built on Chesapeake Bay to permit coal shipments by existing rail systems and oil by sea. The COM would be transported from the production plant to the utilities by barge. The cost of a COM production plant large enough to supply fuel for the generation of 3000 MW (e) was about $300 million. The COM cost also depends on the selection of an optimal combination of available coal and oil to minimize pollution control problems. Preparation of the COM at the power plant site was not considered in this

Table 1
ESTIMATED BOILER LOAD DERATING WHEN FIRING 50/50 COM

Boiler Configuration	Nameplate Capacity on Fuel Oil, MW (e)	Load Derating (%)*	
		Kittaning COM†	Pocahontas COM†
Close-coupled arch	850	27	50
Close-coupled arch	820	20	51
Close-coupled screen	565	36	56
Box	410	56	66
Box	382	58	64
Conventional pulverized coal capable	392	0	0

*Based on the predicted reduction in the maximum rate of steam generation when firing fuel oil.

†Ash fusibility softening temperature: Kittaning coal, over 2700°F (1480°C); Pocahontas coal, 2160°F (1180°C).

study; neither was the effect on fuel cost if a portion of the product is sold to industrial boiler users.

In general, this study shows that conversion to COM can, at best, be expected to provide marginal cost savings to utilities and could easily result in increased power costs. An increase in the calculated cost of conversion resulting from site-specific factors or many changes in the assumptions would be likely to further reduce potential cost advantages gained by switching to COM. Future sharp increases in the cost of oil or specific site considerations may make COM a reasonable option for some utilities. These guidelines, therefore, are provided to enable specific potential users to evaluate the feasibility of converting to COMs. *Project Manager: Rolf K. Manfred*

SOLID BY-PRODUCTS AND HAZARDOUS WASTE DISPOSAL

This is the fourth status report on the activities of the solid by-products and hazardous waste disposal subprogram. A number of project reports have been issued since last year's summary, and these are described below. The previous Journal *reports (May 1981, p. 36; May 1980, p. 43; and June 1979, p. 38) discussed the uncertainty facing utility designers because of evolving EPA waste disposal regulations. This uncertainty still exists. The October 1980 amendments to the Resource Conservation and Recovery Act (RCRA) exempt coal combustion wastes from the hazardous waste provisions for three years, pending the results of an EPA study.*

Sludge and ash disposal manuals

An early product of EPRI's solid-waste research was the *Flue Gas Desulfurization Sludge Disposal Manual,* which was first issued in 1979. The completely revised second edition was issued in September 1980 (CS-1515). A third edition, *FGD By-Product Disposal Manual,* will be published in mid-1982 and will cover dry scrubber wastes as well as sludges.

The second edition of the *Coal Ash Disposal Manual* (CS-2049) was issued in October 1981. The most significant revisions to the second edition are the following.

- The boundary used to define disposal system costs was modified to include in-plant handling systems.

- Provisions were made for the design of collection, storage, and treatment facilities for rainfall runoff from the dry ash storage piles to meet EPA's best-available technology (BAT) limitations.

- Provisions were made for the design of treatment systems for excess sluice water from wet disposal systems to meet BAT limitations.

These revisions were a result of review comments received from the questionnaire included in the first edition.

As part of the effort to prepare the *Coal Ash Disposal Manual,* a computer program, ASHDAL, was developed to generate cost estimates for ash disposal systems. It takes into account varying topographies, siting options, and variable haul distances, and it handles ash quantities ranging from 200,000 to 1,700,000 dry tons per year. The theoretical development of ASHDAL, description of the program, and results from the program (expressed as levelized dollars per dry ton of ash disposed) are included in the *ASHDAL Computer Model for Estimating Ash Disposal Costs* (CS-2368-CCM) available through the Electric Power Software Center.

Both sludge and ash disposal manuals emphasize the construction of new facilities and have only limited usefulness for retrofitting existing waste disposal sites. Work on a design manual to help utilities upgrade existing disposal facilities was completed in 1981. This manual for upgrading existing waste disposal facilities (to be published later this year) assesses current disposal systems in terms of EPA criteria, describes measures needed to bring them up to those standards, and provides procedures and cost estimates for retrofitting. The manual also covers site closure procedures, the conversion of wet disposal systems to dry systems, alternative upgrading procedures, liner design, installation of liners and leachate control systems, cost analysis techniques, and case studies.

PCB disposal

Polychlorinated biphenyl (PCB) detection and destruction projects in the Coal Combustion Systems Division included continued work at Oak Ridge National Laboratory on development of a field instrument for analyzing PCB spills (RP1263-5). Although photoionization detection looked promising initially, it was found that the shift from ideal, pure substances to mixtures of PCBs (e.g., with mineral oil) reduced the sensitivity of the measurement to an impractical level. The focus of the project shifted to a commercially available portable infrared instrument. This device has promise for askarel and PCB spills, and development of a protocol for utility use is planned in 1982.

Another continuing study (RP1263-7) seeks to develop a chemical process for destroying the PCBs in capacitors. The objective is to develop an alternative to incineration. Unlike transformers, capacitors are not easily drained of PCBs because the cellulose interior absorbs the PCBs. The Acurex Corp.'s chemical destruction approach may hold promise. This process uses a chemical treatment similar to that already approved by EPA in a number of regions for PCB destruction in PCB-contaminated oil.

A process that endeavored to clean up spills in situ by chemically accelerating photodecomposition of PCBs turned out to be a more complex system than originally anticipated (RP1263-6). The reaction was not merely dependent on the quantity of chemical reagent versus the amount of PCB present but also appeared to be affected by the nature of the soil. The reaction was successful in solution but not in soil.

Future PCB projects for 1982 include a new approach to portable instrumentation, an attempt to clean up PCB spills with solvents and sorbent material rather than excavating, and another capacitor destruction approach.

Monitoring and modeling

Groundwater monitoring and model development are the tasks of a continuing three-year project (RP1406). The monitoring study is being conducted at the Columbus and Southern Ohio Electric Co.'s Conesville station to assess the performance of the full-scale application of the Conversion Systems, Inc. (CSI), fixation-disposal operation. A report (CS-1984) on the second year of the monitoring program, prepared by Michael Baker, Jr., Inc., under RP1406-2, was published in August 1981. A report on last year's monitoring is in review and will be published later this summer. According to groundwater monitoring data, no leachate has been produced through permeation of the fixated-sludge landfill at Conesville.

Battelle, Pacific Northwest Laboratories has developed a saturated groundwater flow model for predicting the quality and quantity of leachate and its migration path in the disposal area at the Conesville site (RP1406-1). The monitoring data base was used to calibrate and verify this two-dimensional, finite-difference hydrologic flow model for the condition of the Conesville site. In August 1981 a user's manual (CS-2011) was published that describes the use of the variable thickness transient (VTT) groundwater flow code. During 1981 another code was developed for unsaturated flow predictions because many disposal sites have an unsaturated zone between the bottom of the waste (or liner) and the groundwater table. The unsaturated flow code, UNSAT1D, uses a fully implicit finite-difference technique to simulate one-dimensional flow through a partially saturated flow system. The code is capable of simulating infiltration, vertical seepage, and plant uptake by roots as a function of the hydraulic properties of a soil, soil layering, root growth characteristics, evapotranspiration rates, and frequency, rate, and amount of precipitation and/or irrigation. The VTT and UNSAT1D software programs are available through the Electric Power Software Center under licensing agreements.

The basic convective-dispersive transport equation, which has gained widespread acceptance, has inherent limitations for simulating contaminant transport. During 1981 research was initiated to develop a stochastic-convective approach to predicting contaminant transport. In late 1981 the equation formulation and data preparation required to apply this approach to transport analysis were completed. This report will be issued in mid-1982. The two transport model approachs will be compared during 1982; the UNSAT1D model will be coupled with the VTT model and applied to a field site.

Groundwater monitoring for potential contamination from a disposal site is now required in most instances. Proper well location, design, and interpretation of monitoring data are of major importance in reducing the potential for groundwater contamination. In November 1981 a report (CS-2126) was published that surveys the monitoring methods applicable to utility waste disposal facilities and provides recommended procedures.

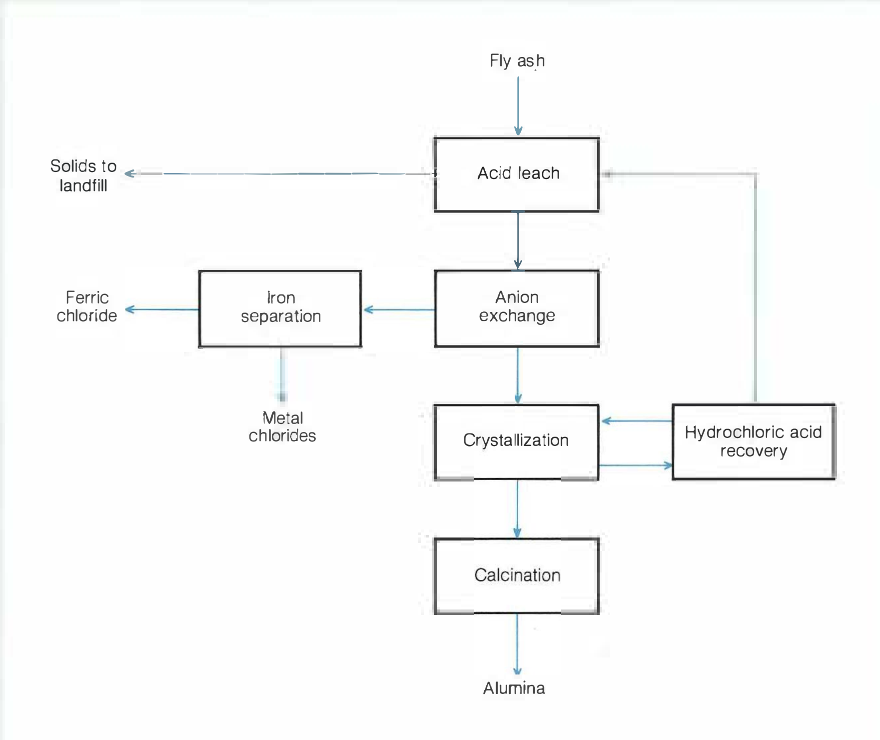
Waste containment

The use of artificial liner materials for waste containment and leachate control is a relatively new practice, so field experience on liner performance is limited. In a project described in detail in the May 1980 issue of the *Journal* (p. 44), fourteen liner materials (six soil admixed liners and eight flexible membrane liners) are being evaluated to determine the effect of long-term exposure to nine types of utility wastes. An interim report is to be issued in mid-1982.

By-product utilization

To complement the disposal manual series, a by-product utilization manual is being prepared by Michael Baker, Jr., Inc. (RP1850-1). The manual will contain a methodology that utility personnel can use in assessing the market potential of their company's coal combustion by-products. By-product marketing will be documented and assessed both regionally and nationally. The report will summarize present utilization practices and anticipated future markets. Publication is scheduled for December 1982.

Figure 1 Hydrochloric acid leach flowchart.



In the last quarter of 1981 the results of the fly ash metal recovery project at Oak Ridge National Laboratory (RP1404-2) were published in a two-volume report (CS-1992). The project report identifies the two most promising removal processes and presents process flowcharts, preliminary designs for a demonstration plant, cost estimates, and expected revenues from recovered resources. In the most promising process, fly ash is leached at about 100°C for two hours in hydrochloric acid to remove the metals. The resultant chloride leachate contains most of the metals, including trace amounts of strategic metals, such as chromium, cobalt, and manganese, but the major components of potential value are aluminum and iron. The leachate is then passed through a series of anion exchange columns to produce a partially purified solution of aluminum chloride. Final purification of the aluminum chloride is by hydrogen chloride gas–sparged crystallization in two or three stages. The final conversion to alumina is accomplished by calcination of the hexahydrate and absorption of the off-gases, which provides recovery of the hydrogen chloride gas and hydrochloric acid for recycle (Figure 1).

Future development work on the process would require better definition of the product purification steps, collection of improved data on the behavior of the important trace metals, and preliminary design and cost evaluation of a pilot unit suitable for installation at a coal-burning power plant.

Regulatory impact assessment

In 1980 EPRI funded an engineering evaluation of disposal alternatives under different regulatory assumptions. The evaluation was based on case studies at representative sites (RP1728). The objectives were to develop well-documented cost data for the EPRI disposal manuals (RP1685), including a computerized cost model, and to formulate a rational basis for evaluating alternative regulatory proposals and their cost impacts. One of the conclusions in this two-volume report, now in publication, is that RCRA legislation and its implementing regulations could have a significant economic effect on the cost of utility waste disposal. Utilities currently spend $800 million a year to dispose of coal combustion solid by-products. If regulations of nonhazardous wastes are finalized in their present form and are strictly enforced by the states, the cost of utility waste disposal could rise to as much as $2.6 billion annually. In the extremely unlikely event that all the combustion by-products are classified as hazardous, the annual expenditures could be $3.4 billion. *Subprogram Manager: Dean Golden*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

Optimal power flow research

Optimal operation of a power system implies minimum cost of operation; at the same time, security, reliability, and equipment-operating constraints must be considered. Because of the size and complexity of today's power systems, computer programs help system dispatchers and planning engineers to arrive at optimal operating conditions. Not only real power flow but also reactive power flow and bus voltages must be scheduled if the power system is to be operated as efficiently as possible. And now, rising fuel costs, questionable fuel supplies, decreasing system reserves, and limited operating budgets have created conditions that must be simulated more accurately for proper resolution. The speed and accuracy of advanced computers can be enlisted to do this. However, it is necessary to consolidate needs of the application before a computer can be used effectively.

Three groups of application areas exist.

- System planning—the available power system equipment is fixed at any given time, and the solution time is not critical.
- System operations—the same equipment is available, but the computer solution time is critical.
- Resource planning—additional resources are available and may be added or retired over time, but the solution time is, again, not critical.

The intent of the first phase of a recently funded research project on optimal power flow (RP1724) is to develop a set of recommendations for large-scale, optimization-type computer programs. A questionnaire and utility interviews will provide application and user requirements, and a literature search will be made to determine the best solutions for each application. The larger issues to be addressed here are the potential applications and the solution procedures. This first phase is also intended to identify both planning and operations (including real time) requirements for the optimal power flow. The results will include a handbook on optimization for power system planning and operations.

Energy Systems Computer Applications, Inc., is the contractor for the first phase of the project, which is scheduled for completion in mid-1983. The final goal is to develop large-system production-grade programs during the second phase for distribution by EPRI's Electric Power Software Center. *Project Manager: John W. Lamont*

DISTRIBUTION

Laser detection of voids and contaminants

Cross-linked polyethylene (XLPE) is the insulation material most widely used in new underground distribution cable. However, voids and contaminants in XLPE can cause premature cable failure. Industry specifications attempt to eliminate voids and contaminants that are 2 mils (51 μm) or larger. The current inspection technique is to conduct partial discharge tests on reels of finished cable. Although this technique can detect a single 2-mil void in a 5000-ft (1524-m) length of cable, it has several important limitations. For example, it can detect neither contaminants and flaws nor voids internally shielded by vapors and liquids; nor can it locate the defective portion in a cable or be used online to perform real-time inspection during manufacture.

A project with United Technologies Research Center (RP794) has developed a new system for XLPE cable insulation inspection that does not have these limitations. This system uses a far infrared (FIR) laser beam to penetrate the XLPE, which is transparent to laser light at the wavelength chosen (119 μm). The focused FIR laser beam scans the cable insulation in a 360° angular motion by a rotating mirror system at a rate high enough to ensure complete coverage while the cable is moving at normal extrusion speeds. If no defects are present, the laser beam penetrates the insulation without scattering. If defects are present, the laser beam will be scattered (Figure 1). An optical tracking system collects the scattered laser energy and signals the presence of a defect.

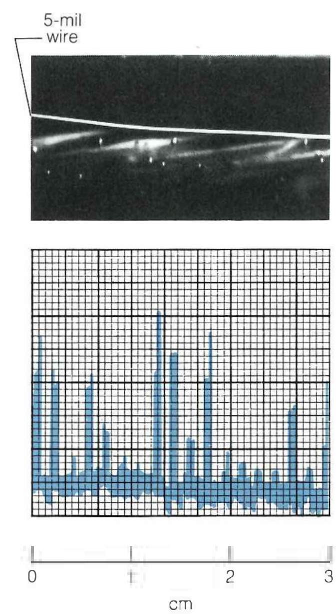
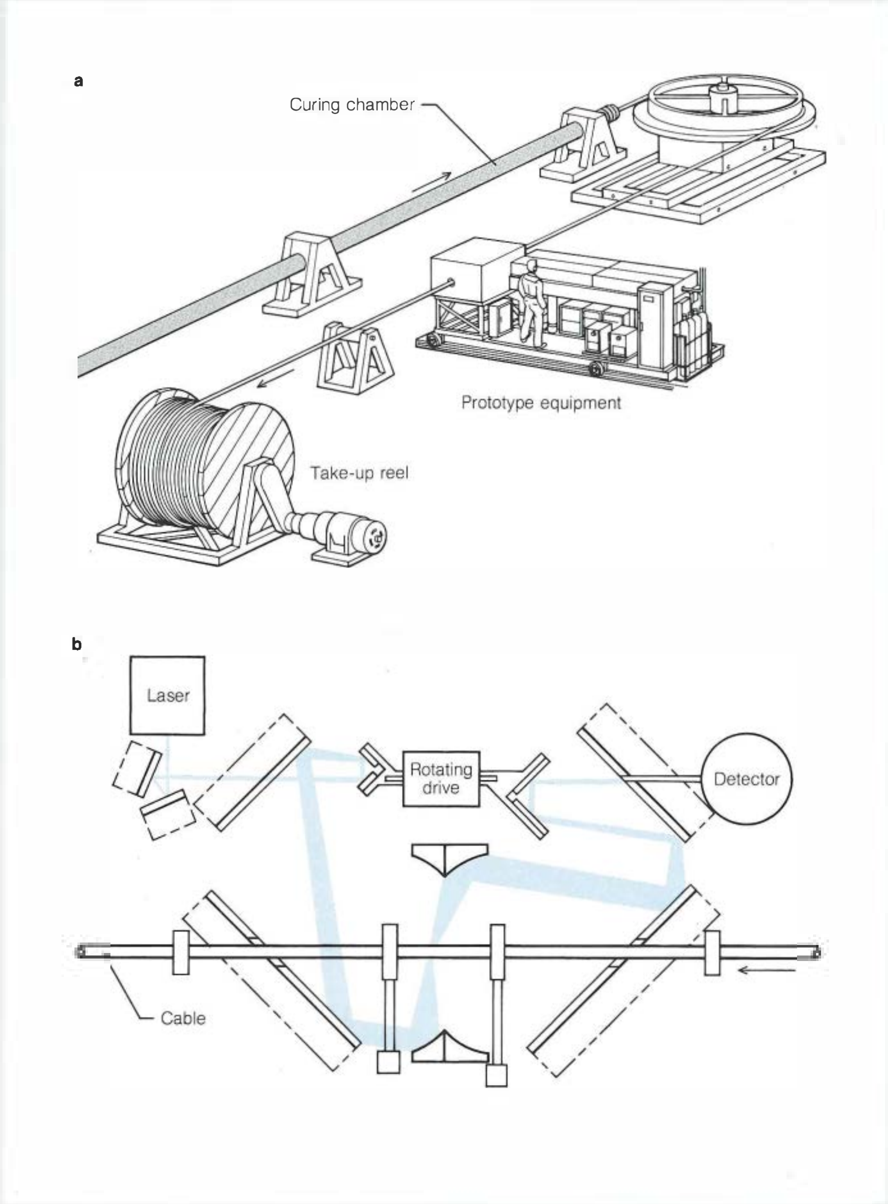


Figure 1 At top is a sample of solid dielectric cable insulation that has been rendered transparent by addition of an oil. The voids and contaminants that are visible to the eye are matched in location and size by traces on the graph; these traces were caused by scattering of a scanning laser beam. The 5-mil (127-μm) wire was laid on top of the cable as a size reference.

At present a laboratory prototype has been constructed to demonstrate the FIR inspection system. This laboratory cable inspection equipment has demonstrated that it can inspect the insulation of 25-kV distribution cable with conductor sizes ranging from No. 2 solid to No. 1/0 stranded, with at least 95% coverage at normal extrusion speeds. The smallest detectable defect size in a 25-kV, 1/0 XLPE cable is about 2 mils. The instrument has also demonstrated that it can detect voids, contaminants, conductor shield protrusions and fall-ins, and defects on the surface of the insulation.

Work is now proceeding to construct a system designed for use in a cable factory environment. Figure 2 is a conceptual diagram of this system. It is expected that this system will be built and made operational at United Technologies Research Center by mid-1984. It will then be installed in the Essex Power Conductor Division of United Technologies Corp., where it will be evaluated under conditions representing on-line inspection of XLPE cable production. *Project Manager: Joseph Porter*

Figure 2 **(a)** Conceptual drawing of a far infrared (FIR) laser cable inspection system installed in a cable factory; **(b)** detail of optical scanning by an arrangement of rotating mirrors in prototype equipment.



Metering interference

Utilities are expected to accurately measure all energy consumed by customers. If the meter underregisters, the customer does not pay for all of the energy consumed and the utility loses revenue; if the meter overregisters, the customer is unfairly overcharged. Both utilities and regulatory agencies are vitally interested in knowing precisely how accurately the meter can measure harmonic energy and to what extent the distribution system noise and harmonics interfere with accurate metering on power systems. For example, it was desirable to determine if the future application of such devices as dimmer switches, battery chargers, and motor controllers would produce harmonics and electrical noise on distribution systems to the extent that they could affect meter accuracy.

The principal objective of a recently completed project was to measure and evaluate the effects of noise and harmonics on the accuracy of the induction watthour meters presently in service throughout the United States (RP1738). Several types of self-contained, class 200 single-phase and three-phase meters from the four major meter manufacturers—General Electric Co.; Westinghouse Electric Corp.; Sagamo Weston, Inc. (Schlumberger, Ltd.); and Duncan Electric Co. (Landis & Gyr)—were tested. Three each of five of the most common types and models from the four major meter manufacturers (total of 60 meters) were used to determine the way in which amplitude, frequency, and phase of the voltage and current waveforms affect meter performance.

Two principal conclusions resulted from the tests.

- The induction watthour meter does not accurately measure the harmonic power content that exists in a distorted current and voltage waveform.
- The presence of such harmonics generally does not cause overregistration or underregistration outside meter standards for measurement of power at 60 Hz.

The results of the 150 references that were reviewed were consistent with the results of this research, although this research was more comprehensive than that conducted in the references. In summary, for most applications (harmonic content less than 3% of total power) the induction watthour meter does register within standards. However, the test results do show that if a load produces high harmonic content (greater than 10% of total power), the meter will generally underregister total power because it will generally underregister the harmonic power. *Project Manager: William E. Blair*

OVERHEAD TRANSMISSION

Dc conductor development

The final report of a project on dc conductor development (RP1514) is available for distribution (EL-2257). This project had an ambitious objective: to develop an improved conductor for use on HVDC transmission lines that would take advantage of any unique characteristics of dc. Although design of conductors is a mature technology, several promising new concepts were proposed. For example, a self-filtering conductor might be made by placing the high-impedance reinforcing steel on the outside of the conductor, where the harmonic component of the dc current would be attenuated by skin effect. The hope was that this could reduce or eliminate the cost of converter station filters. Analysis of this concept by computer models showed only marginal reduction of harmonics, and the conductor would be less cost-effective than conventional conductors and filters at the terminals.

The results of the project did indicate promise of improved dc conductors in two general areas: conductor designs reducing or eliminating the emission of ions from the conductor surface, and conductor configurations that would reduce or eliminate ion current to ground.

Examples of the first are insulated conductors or conductors with semiconductive coatings. For new conductor configurations, the designs showing promise are a vertical pole configuration using the same or different pole voltage, corona-emitting grounded shield wires underneath the poles, and dissimilar poles where the positive pole would have a bundle of more conductors than the negative pole. Some of these configurations will be investigated in 1982 on the full-scale HVDC test line at Project UHV (RP1282-2).

Final Report EL-2257 contains new information on the physical mechanisms of corona on the surface of dc conductors and how this corona can be controlled.

Although the bold objective of developing an improved conductor was not realized, our understanding of the physics of corona on dc conductors was significantly enhanced, as was our potential ability to control ion currents. *Project Manager: John Dunlap*

Transmission line mechanical research facility

A transmission line mechanical research facility (TLMRF) is now under construction in Haslet, Texas (RP1717). Ebasco Services, Inc., of New York has been retained to design the facility and provide advisory services. Adelphon, Inc., of Ft. Worth will own and operate TLMRF. The facility should be completed in 1982 and will consist of three test areas: a two-mile transmission line, a foundation test area, and test pads and reaction frames. The TLMRF should permit the utility industry to perform needed transmission line research and development activities in a timely and cost-effective manner.

The test line (not energized) will be used for broken wire tests, stringing trials, maintenance experiments, and artificially induced conductor vibration experiments. This particular facility can be used to define loads and to measure structure response. Portable as well as fixed instrumentation will be on hand.

The foundation area can be used in several ways. Several types of foundations can be tested and compared in the soil type native to the site. From these tests, techniques and equipment for field testing can be developed. Then, of course, the sandbox approach can be used by scooping out certain areas and backfilling with specific soil types. This can be particularly useful in developing response characteristics as a function of soil parameters. Finally, a full-scale tower can be mounted on a real foundation and the complete system tested.

A test pad–reaction frame will be used for static as well as dynamic (time-varying) load testing. From the dynamic load testing, EPRI will characterize structure response and develop equivalent static loads that can be used in future proof tests. All loads will be computer-controlled and applied in any desired sequence or pattern under software/feedback control.

There are two test pads, with the capability of adding a third (Figure 3). Test pad No. 1 is 75 ft² (7 m²) and No. 2 is 50 ft² (5 m²). Test pads 1 and 2 will be 4 ft (1.22 m) thick and 3 ft (0.914 m) thick, respectively. They will be supported by piers 2 ft (0.61 m) in diameter, which will extend into a blue limestone bed for a distance of 18 ft (5.5 m). The limestone

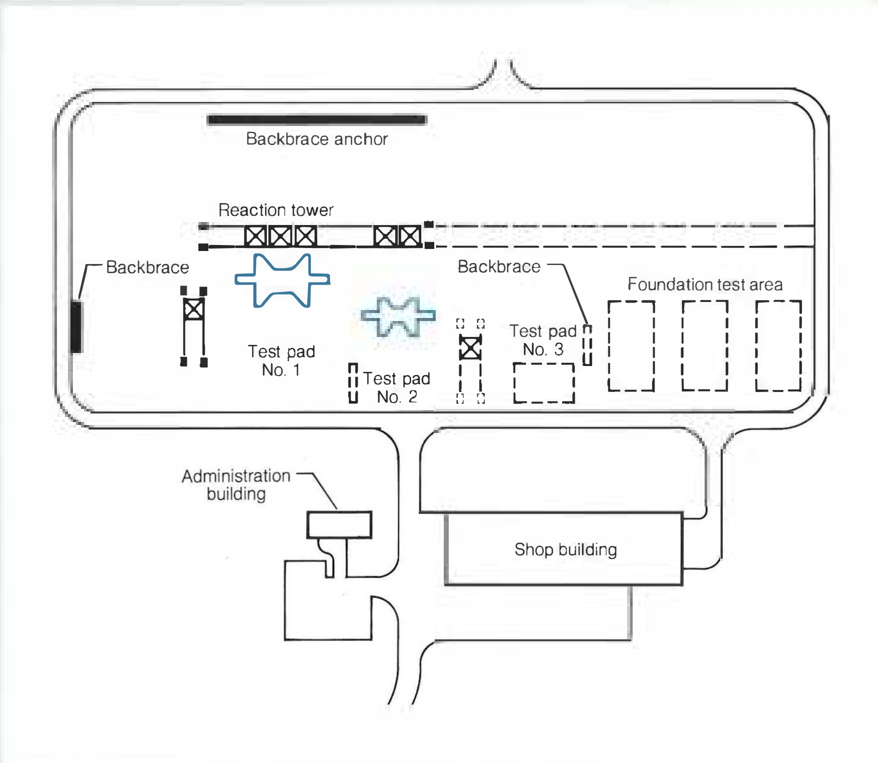


Figure 3 The foundation test area consists of two test pads and six movable reaction towers that are 180 ft high. (Future construction is indicated by the dashed lines.)

begins approximately 10 ft (3 m) below the surface. The pads will have specially designed anchor insert clusters, generally on a grid pattern 4 ft on center in each direction. These anchor devices will be used to mount winches for vertical loads and to fasten the legs of test towers to the pads. Current design calls for a 200-kip (890-N) working capacity for each cluster.

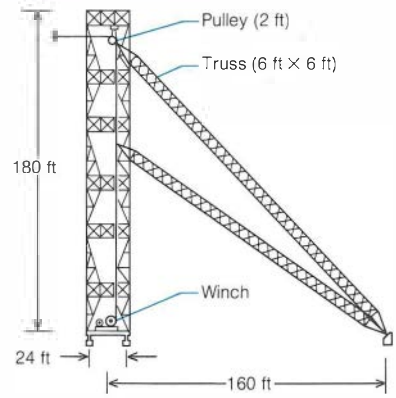
Reaction frames used in applying loads to a test specimen will be in both the transverse and longitudinal directions—four longitudinal and two transverse. Initial height will be 180 ft (55 m) with expansion capability to 240 ft (73 m). One of the unique features of these frames is their ability to line up with attachment points on a test specimen. Another interesting feature is the tie-back tension trusses that are used to decouple the horizontal load transmitted from the test specimen to the frame (Figure 4). This forces the horizontal load down the truss to a tie-back rail and foundation, and thus the reaction frame is exposed only to compressive loads. The decoupling is accomplished by connecting the tie-back truss to a pendulum (hanger) from which the load-carrying pulleys are supported. Hangers will be located at the 165-ft, 105-ft, and 45-ft (50-, 32-, and 14-m) levels. When future testing requirements dictate an additional 60-ft (18-m) module on top of the reaction frames, a pull-off can be attached at the 225-ft (68-m) level.

Loading criteria for design of the reaction frames were based on estimated loads for 1200-kV tangent towers. If some future load requirements exceed those assumed in design, the mobility of the reaction towers permits their being grouped and tied together.

One of the most significant capabilities of TLMRF will be its dynamic test ability. Early in design it was recognized that the dynamic response of the reaction/tie-back system was critical. Knowledge of the reaction structure characteristics was necessary to plan dynamic tests. To discover and solve any potential problems, a series of dynamic analyses were performed on the tie-back system. These analyses determined the critical structural responses when the tie-back system is subjected to the proposed sinusoidal dynamic test loadings.

The basic philosophy of load application is that load points on the test specimen are served by from one to three cables, generally oriented along transverse, longitudinal, and vertical axes. The angular orientation of the load vectors at the load point will be established by pull vector orientations and magnitudes. The magnitudes are monitored with a tension transducer. The cables are attached through the transducers to the load point and thus establish the pull vectors. The cables then are led through sheaves to winches, which are controlled by a computer. The computer will continuously calculate the load vector and compare it with the desired vector. Then the computer will call for corrections by initiating winch action.

Figure 4 The movable reaction towers have tie-back tension trusses that decouple the horizontal load transmitted from the test specimen to the frame, forcing the horizontal load down the truss to the tie-back foundation.



Over the next 10 years the utility industry will be able to make great strides, advancing both the state of the art and the state of practice through research conducted at TLMRF. Analytic models will be improved, new analytic techniques will be developed, and all will be verified by full-scale testing, using the most advanced computer control and data acquisition. The bottom line for the utilities will be lower costs with predictable reliability. *Project Manager: Paul Lyons*

TRANSMISSION SUBSTATIONS

Semiconductors for EHV switching applications

The development of power-switching semiconductors for use under surge conditions has resulted in two distinct devices. General Electric has developed a photo transistor that handles several orders of magnitude higher power than any previous photo transistor (RP1511-1). The device carries 200 A with a 50% duty cycle; it has a 1000-V breakdown, which is quite high for a transistor. It also can handle a 500-A, 5-ms surge. Although these are significant achievements, they (along with the inherent switching capability of the transistor) still are not enough to permit use of the device in EHV switching. This project has been terminated, and the work is being documented for possible use in lower power applications.

General Electric is now developing a surge, light-triggered thyristor to handle surge currents (RP1511-2). Extensive modeling has shown the feasibility of designing an asymmetric thyristor with a steady-state rating of 2000 A and a forward breakdown over 10 kV. Surge current rating may possibly be as high as the 100 kA seen in a breaker. In the asymmetric configuration, the thyristors are required to block voltage in one direction only. They are thinner and have a different doping profile than normal thyristors. Of course, they do require backup by series diodes to block the reverse voltage. Computer models have determined the desired doping profile, and laboratory trials to realize the proper doping level and junction depth are going forward.

Success in developing a 10-kV, 2000-A asymmetric light-triggered thyristor may provide significant fallout in the future for an HVDC valve. Because there would be fewer junctions, a 10-kV asymmetric thyristor backed up by a 10-kV reverse diode would have lower losses than two 5-kV symmetric thyristors in a similar circuit. Any advances made in the companion project (RP669-2, light-triggered thyristor, also with General Electric) in the area of protection against high di/dt and internal protection against forward voltage breakover will be applicable to the asymmetric device. *Project Manager. Gilbert Addis*

UNDERGROUND TRANSMISSION

Flexible gas-insulated cable

One of the new technologies being developed for efficient, high-capacity, underground transmission cable consists of a gaseous dielectric inside a reelable, flexible enclosure made of aluminum.

Under a prior contract with Brown Boveri Corp. (RP7837-1), EPRI funded the development of a cable-fabricating machine that can produce a flexible, SF_6-insulated coaxial cable rated 230 kV or 345 kV. In an effort to provide low-cost cables that would match overhead lines rated 500 kV, a follow-on project (RP7890) was undertaken with Brown Boveri, using its UNIWEMA-450 cable-fabricating machine (Figure 5). The standard output from this machine (a 390-mm-diam,

Figure 5 The UNIWEMA-450 can manufacture 230-kV and 345-kV cable in 100-m sections. Shown here is the machine forming the 390-mm enclosure as the flexible conductor is placed inside, with the spacer insulators attached. Lengths of more than 100 m could be made continuously; however, reel sizes would be prohibitively large and nearly impossible to ship by truck or rail.

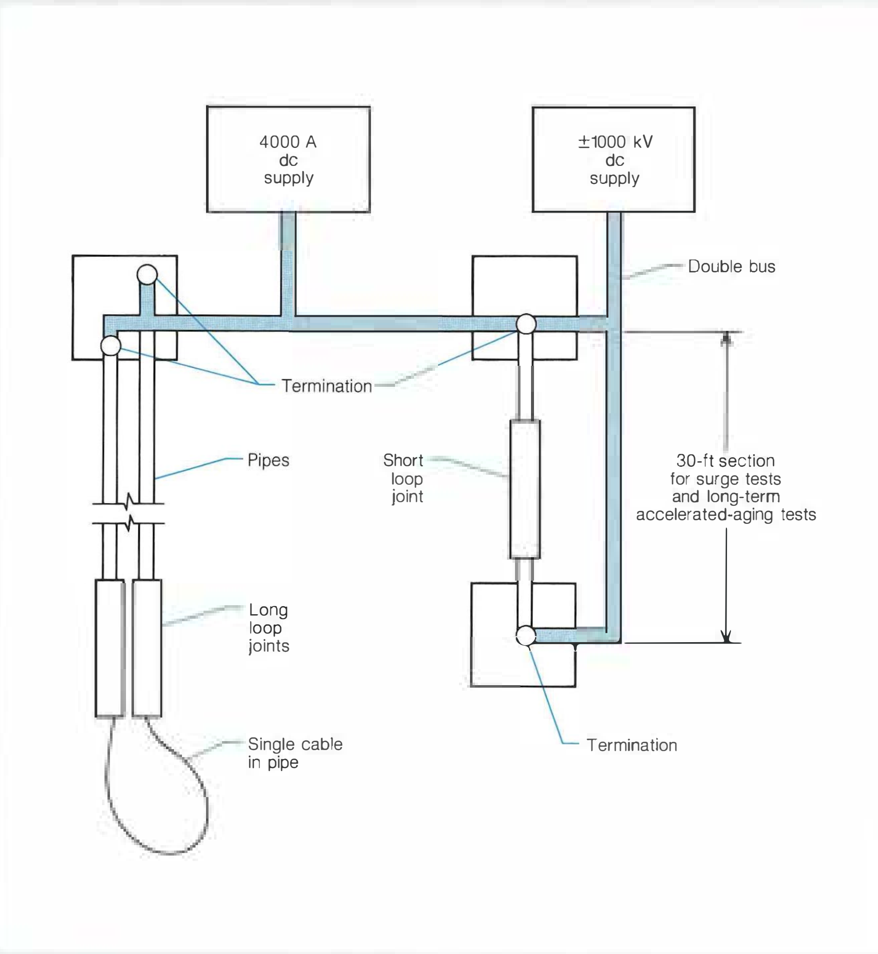


Figure 6 Simplified layout of Waltz Mill dc test area. The long test section is limited to aging tests, and the shorter section, to surge and aging tests.

15.4-in-diam, corrugated aluminum tube), which is designed for 345 kV, was tested by Brown Boveri for application at 500 kV. The impulse, switching surge, and ultimate ac withstand tests indicated that a 500-kV, SF_6-insulated cable should have a 450-mm (17.7-in) enclosure at 310 kPa (45 psig) to ensure the 1550-kV basic impulse level required for utility applications. Even so, the 390-mm (15.4-in) enclosure's near-500-kV performance ensured its reliability at 345 kV.

Details of the design for a 500-kV flexible gas-insulated cable are available from the final report to be issued in mid-1982. The 345-kV and 230-kV cables can now be available for utility applications.

Details on the RP7837 project covering the development and testing of the 230-kV and 345-kV systems will be in a final report to be issued shortly. The UNIWEMA-450 manufacturing machine is currently on standby and is available for sale to a manufacturer. *Project Manager: Thomas J. Rodenbaugh*

Waltz Mill

The Underground Cable Test Facility at Waltz Mill, Pennsylvania, under lease to EPRI, is undergoing a major addition to its testing capability. The facility was originally designed for and limited to testing of ac prototype cable systems. However, with the relatively recent successful development of thyristor valves, underground dc transmission has become a reasonable alternative in certain situations.

The design work for erecting dc test equipment, a test bus, and an initial test bay was completed in 1981, and station modifications are nearly complete. A simplified layout of the modifications is shown in Figure 6.

When completed, the dc test bay will have a voltage supply capable of energizing test samples up to ±1000 kV dc. A separate dc current supply will be capable of circulating up to 4000 A in a cable loop while the sample is being energized. Because the switching surge requirements of dc cables are an important design consideration, the dc test bay has been designed for superimposing switching surges on top of the dc test voltage. A small control building will be erected for housing control equipment and a remote data acquisition system for the dc tests. The remote data acquisition system will then transfer data to the central computer.

The first cable to be tested in this area will be a prototype ±600-kV dc pipe-type cable that was developed by Phelps Dodge Cable & Wire Co. with DOE sponsorship. This test is scheduled to begin in late 1982. *Project Manager: John Shimshock*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

MICROCOSMS FOR ECOLOGICAL STUDIES

In the fall of 1980, EPRI sponsored a workshop on cycling and effects of toxic substances (EA-1988). The major objective of the workshop was to develop a basis for planning the toxic substances subprogram of the Ecological Studies Program. One workshop recommendation was the funding of microcosm research to develop tools and methodologies for ecotoxicologic research. A high-priority research topic identified by the workshop was determining quantitative and/or qualitative relationships between ecological field testing and bioassay/microcosm testing through the development of better analytic methods.

The development of a framework to assess the ecological effects of the effluents from power plants has been a major objective of the Ecological Studies Program. The tools applied to this task have included single-species laboratory tests or bioassays, multispecies, multicomponent microcosm tests, field studies, and mathematical modeling. Single-species tests are relatively simple to conduct under controlled conditions and they are also easy to replicate. However, single-species tests may not represent ecological reality very closely. Field studies have a high degree of ecological realism, but they cannot be controlled and are difficult to replicate. Microcosms represent a middle ground. They can be controlled and repeated, and they have a higher degree of ecological realism. There are three major types of microcosm work in the EPRI Program: lake microcosm (RP1910), agricultural microcosm (RP1224-5), and stream microcosm, a project that is being initiated during the second quarter of 1982. This report will focus on the progress to date of the agricultural microcosm project.

Agricultural microcosm

A two-year research project, begun in November 1978, evaluated microcosms' usefulness in assessing the response of terrestrial ecosystems to fly ash emitted from coal-fired power plants. At the end of the two years, a three-year follow-on effort was initiated. This project evaluates microcosms as a screening tool for assessing the effects of utility industry waste products by varying such parameters as soil depth, microcosm diameter, and type of waste product. The work will also evaluate the use of precipitator fly ash as a soil amendment.

The microcosms used in this study consist of soil cores 17.5 cm in diameter taken from an agricultural field. In the first two years of the study, the cores were 30.5 cm in length and obtained by pounding a polyethylene tube into a trench from which plowed topsoil had been removed. The resultant 10 cm of intact (undisturbed) subsoil was overlaid with the plowed topsoil in a manner duplicating the typical plow depth of a midwestern agricultural ecosystem. The microcosms were then transported to a greenhouse. The bottom of the subsoil of each unit was leveled, and a thin layer of glass wool applied to the bottom. The microcosms were then placed on a porcelain funnel in a movable cart, and Styrofoam was packed around the six microcosms contained in each cart (Figure 1). In the current study, microcosms 61 cm in depth are being used in a similar setup.

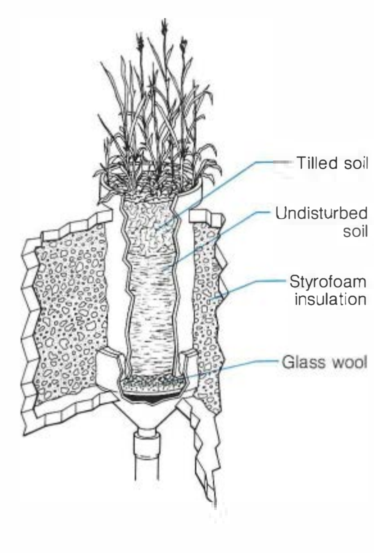


Figure 1 Cutaway of agricultural microcosm in insulated cart.

An important aspect of the agricultural microcosm work has been the comparison of the microcosms with field plots. Field plots were staked out and plowed in the same field from which microcosm soil cores were removed. In the first two-year study, 1.2-m-diam circular plots were used for comparison with microcosm data; larger (9-m^2) plots were prepared for the present work (Figure 2). The plots were encased (wrapped on the sides) with plastic to prevent migration of treatment agents between plots. Plastic tubes (lysimeters) with porous ceramic cups at the bottom were placed in the field plots at the same depth as the microcosms in order to collect soil water by suction pump.

The field plots and microcosms were planted with a mixed-species crop. During the first two years an alfalfa-clover mixture was used. The crop planted for the current program includes alfalfa, timothy, and oats. Timothy and oats were chosen because of their sensitivity to trace elements in fly ash and because the seed head of oats is used for human consumption.

Figure 2 Field plot layout (5 × 5 Latin square) for 1981–1983 research using precipitator fly ash and boron as treatments.

Treatments and results

During the 1979–1980 study, three levels of stack fly ash (collected from stacks after the electrostatic precipitator) were applied to the microcosms and field plots after a crop had been established. The ash was applied at rates of 5, 9, and 27 t/ha, using a specially constructed machine that uniformly distributed the ash over the microcosms and field plots. These application rates corresponded to calculated deposition rates for 5, 12, and 36 years, respectively.

To determine the effects of the three levels of fly ash treatment on the microcosms and field plots, treated and untreated units were evaluated periodically. The three evaluation methods included crop yield (productivity), nutrient stripping (loss in soil water), and trace element fate (uptake in plant tissues). Monitoring methods used in the field were as close as possible to those used in the laboratory, so that the resultant data between experimental units could be compared to determine the ability of microcosms to predict field effects. Plant productivity was assessed by harvesting and weighing air-dried plants to determine the net primary productivity. In 1980 the alfalfa-clover crop was harvested three times during the growing season.

Crop yields during the 1979–1980 research were quite high in both the microcosms and field plots. In fact, the air-dried yields of the alfalfa-clover crop were well within the range for farm yields reported by agronomists in Ohio. Thus both experimental units appeared to track real agricultural systems in terms of total yield.

None of the three levels of treatment used in the 1979–1980 research significantly affected air- or oven-dried yields in either microcosms or field plots. Because there were no differences between treatments, data for the oven-dried crops for all microcosms and all field plots were pooled. This net primary productivity data showed that differences in yield between the two experimental units were not significant.

Nutrient loss in microcosm leachate and field plot soil water was measured to evaluate the extent of the ecosystem disruption caused by different treatment levels of fly ash. Six nutrients and pH were analyzed in soil water from both experimental units. However, only three of the nutrients (calcium, potassium, and nitrate-nitrogen) were present in soil water in sufficient concentrations to be detected by standard analytic equipment. Increased nitrate-nitrogen loss in soil water appeared to be the best nutrient indicator of ecosystem disruption caused by fly ash deposition.

Trace element uptake by crops grown on control and fly ash–treated plots was monitored by analyzing the oven-dried material harvested periodically for the productivity studies mentioned above. Plant tissue concentration of 5 of the 16 trace elements analyzed was found to be significantly higher in the highest-treatment level compared with undosed controls.

Three of the elements (arsenic, chromium, and selenium) showed significantly higher levels in both the microcosms and field plots. Two elements (nickel and strontium) showed significantly higher levels in microcosms but not in the field plots. In general, however, the microcosms did an excellent job of predicting plant uptake or lack of uptake of trace elements by field-grown crops.

Continuing research

Although the 1979–1980 research indicated that the agricultural microcosm is a useful tool for predicting ecosystem effects of waste materials, a number of refinements in microcosm design and other experimental procedures are being implemented and tested in the present program. Some of the refinements are the evaluation of optimal depth and diameter of microcosm units, improved methods for collecting soil water for leachate testing, and new monitoring methods, including carbon dioxide evolution. A positive control (boric acid) is being used in conjunction with the fly ash testing. The emphasis of the fly ash testing project has changed from assessing effects of airborne desposition of stack fly ash to evaluating effects of treatment with much higher levels, up to 700 t/ha of precipitator fly ash. Other waste products, including scrubber sludge, will be tested during this phase to determine whether different nutrients are appropriate indicators of the effect of materials other than fly ash on soils. *Project Manager: Robert Brocksen*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

ENERGY CONSERVATION WITH PCC SYSTEMS

Customer equipment frequently requires electricity in a form other than the 60-Hz waveform provided by utilities. Power-conditioning and control (PCC) systems are used to condition the electricity to dc or to a waveform of another frequency. In recent years, power semiconductors used in PCC systems have been significantly improved in cost and performance. Rising energy costs and declining costs of PCC systems are providing the impetus for new and more energy-efficient customer applications. However, improper application of PCC systems can cause serious problems for customer equipment and could degrade utility waveform quality. Recognizing the potential problems, EPRI has initiated several projects.

Recent advances in semiconductor technology have been most evident in low-level information-processing circuitry. Improvements in technology have been especially noticeable in communications, microprocessors, computer memory, signal processing, and control. Power semiconductors have been significantly improved in terms of costs, operating capabilities, and fabrication techniques. The latest generation of power semiconductors will likely find many new applications that save considerable energy.

PCC circuits require switches that turn off and on to produce a desired waveform. Power semiconductors are used as switches in PCC systems. Many power semiconductor devices are arranged in series and parallel and require high switching efficiency to be effective. Two categories of power semiconductors are used for this switching function: silicon-controlled rectifiers (or thyristors) and transistors.

SCRs are still the workhorse for the high-power area (>100 hp; >74.6 kW). These devices have attained the highest voltage and current capabilities. Although an SCR is relatively easy to turn on, it is difficult to turn off and rather slow in switching between on and off states. Two promising SCR derivatives—gate turn-off (GTO) devices and field-controlled thyristors (FCTs)—have recently been developed. However, while these SCR derivatives are expected to be important in future systems, they are not currently available in sufficient quantity for accurate characterization.

Until recently, metal oxide silicon field-effect transistors (MOSFETs) were associated with low-power, logic-type circuits. Power MOSFETs capable of efficient switching at several kilowatts are available. It is already clear that they will displace bipolar transistors in many high-frequency applications. Transition time between on and off states is on the order of nanoseconds. This compares with microseconds for bipolar transistors and results in lower power dissipation during switching. The power to control a MOSFET is almost negligible; however, the on resistance is high. Further, MOSFETs can be paralleled much more easily than bipolars—current flows equally between MOSFETs, as opposed to the "current hogging" of bipolars. This eliminates the need for ballasting resistors and device matching, thus increasing reliability and lowering costs.

Microprocessors and their extensive use in the industrial and commercial sectors have created a demand for power integrated circuits that can interface between the low-level microprocessor output signals and the switching device that handles the power. Now that MOS processing has entered the power semiconductor arena, it becomes practical to consider synthesizing power integrated circuits by using compatible MOS technology (in other words, digital or linear circuits, along with power devices, could be fabricated on the same chip).

There have been improvements in the packaging and process technology for bipolar transistors, and thermal resistance and power-handling characteristics have benefited therefrom. Incorporating a small transistor to drive a large transistor produces the Darlington transistor, which exhibits better gain and switching characteristics.

Gallium arsenide (GaAs) field-effect transistors, used in microwave power amplification, have been well established over the last decade, but their potential in power devices has been overlooked until recently. In general GaAs devices with equal power-handling capabilities can be eight times smaller than their silicon counterparts. Device packaging and gate drive circuitry can be simplified. Although fraught with technological difficulties, these devices show great potential in high-frequency applications.

Figure 1 shows the predicted power-handling capabilities of various devices by the year 1990. MOSFETs will be used in low power, high-frequency applications. Bipolar transistors will become popular in low-to-medium power, lower-frequency applications. GTOs and FCTs will be effective in the medium-to-high power range.

Energy-saving applications

A project on the impact of advanced power semiconductor systems on utilities and industry was initiated to define the applications foreseen to have significant use by customers (RP1201-12). The study found that many applications will exist for the latest generation of power semiconductors, including the following.

- Switching-power supplies—used by electronic equipment as a dc power source (e.g., television, computers, copiers, word processors)
- High-frequency fluorescent ballasts—used in lighting to reduce current flow
- NASA power factor controller—a simple and inexpensive circuit that improves power factor of induction motors operating below full load
- Ac synthesizers—used principally in variable frequency and variable amplitude inverters for variable speed drives with induction motors

The workhorse of the dc power supply business has been linear, series-pass regulated supply. The major disadvantage of this type of power supply is the variable resistor type of control—excess voltage and current is dissipated as heat. Switching-power supply, the series-pass supply counterpart, operates 20–25% more efficiently and is smaller in size.

High-frequency ballasts are expected to

replace the iron core inductor ballasts now widely used in fluorescent lighting to limit current flow. This PCC system generates frequencies in the 15–20 kHz range, a range in which fluorescent lamps operate more efficiently. Fluorescent lamps have dominated almost three-fourths of the commercial and industrial lighting applications. Fluorescent lighting consumes approximately 70% less electricity than its equivalent incandescent counterparts and lasts much longer. With the high-frequency ballast, an average of 22 W can be saved, compared with a traditionally ballasted 100-W fluorescent installation.

The largest energy savings is expected to come from ac synthesizers used as inverter drives in ac induction motors to vary the motor speed. Although inverter drives have been available for over 25 years, their cost was prohibitive. The rising cost of energy and the declining cost of power electronics have changed the economics of application. The ability to retrofit an ac-driven pump or fan with an inverter represents an area of significant potential for energy conservation. The energy saved is highly dependent on size, duty cycle, and overall efficiency. In general, pumps that are heavily throttled or fans that are extensively dampered offer the greatest energy savings.

Each of these PCC systems can be cost-justified on energy savings and/or operational flexibility. Because sufficient financial incentives exist for end users to purchase PCC systems and the applications are large in number, significant national energy savings will result. The energy-conserving aspect of these PCC applications was forecast by RP1201-12 for the years 1985, 1990, and 2000 (Table 1).

Table 1
U.S. ELECTRIC ENERGY SAVINGS FROM PCC SYSTEMS
(10^9 kWh annually)

	1985	1990	2000
High-frequency ballasts			
Residential	*	0.4	2.1
Commercial	0.4	15.4	25.6
Industrial	*	0.9	2.1
Switching-power supplies			
Residential	*	*	*
Commercial	1.7	4.3	8.7
Industrial	*	*	*
Ac synthesizers			
Residential	*	*	*
Commercial	0.3	2.9	34.3
Industrial	*	41.4	107.7

*Less than 0.1 × 10^9 kWh.

Follow-on work

The application area of greatest potential energy savings is the new design and retrofitting of pumps and fans with inverter drives, where appropriate. Customer economic incentives appear to be greatest for this application; hence project development has moved into this area. Under a project on variable speed drives for pumps (RP1966), an energy audit is being conducted in the industries that use pumps most often (electric utilities themselves consume more shaft horsepower than any other industry). Plans to retrofit the pump applications found during this project include installing both commercially available and advanced-design PCC systems.

Additional EPRI projects are studying other PCC system applications, including fans, compressors, and heat pumps. For example, a feasibility study of variable speed drives for heat pumps will focus on inverter drives for modulating heat pump capacity (RP2033-4). Another EPRI project on an advanced two-bridge power conditioner for batteries, fuel cells, and alternative applications is investigating the use of an advanced fuel cell–battery inverter as an adjustable speed drive for a utility oil-fired combustion forced-air fan (RP1464-1).

Although the potential benefits appear attractive, manufacturers and users have concentrated their design efforts on the load-device interface, with little attention devoted to the utility interface. Harmonic voltages/currents, a low power factor of operation, and EMI generated by PCC systems can lead to a degradation in the present quality of grid power. No guidelines that define tolerable levels of harmonic content and EMI have been established by utilities. It is therefore important, especially in the early stages of device introduction, that utilities and manufacturers cooperate to produce the lowest-cost PCC systems for users, while maintaining the high degree of quality and reliability characteristic of today's electrical energy supply. *Project Manager: John Brushwood*

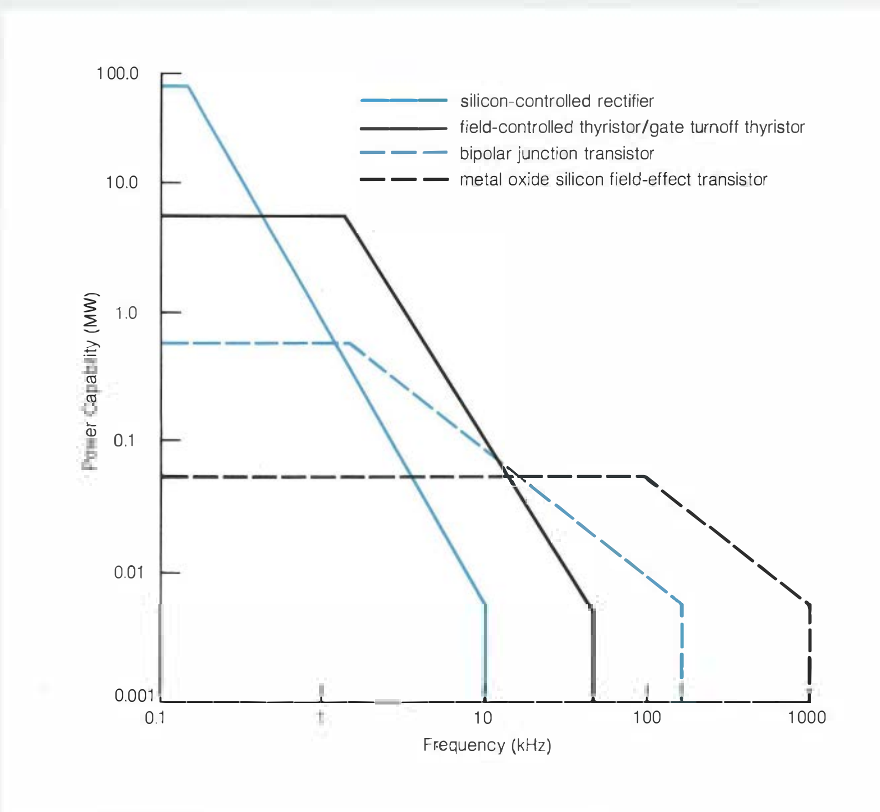


Figure 1 Predicted power-handling capabilities of various devices by 1990.

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

GENERIC SAFETY ANALYSIS

The NSAC Generic Safety Analysis Program supports the utility industry in evaluating the importance of potential safety problems that have been identified. These problems generally have the following characteristics: Elements of the problems are common to at least several plants; a comprehensive and sophisticated analysis is required; the problem solutions have plant design relevance over the long term.

There are three major steps in the generic safety analysis process: tracking, evaluation, and implementation.

▫ NSAC concentrates on only a few generic safety problems at one time, but there is a continuing need to collect and monitor information that is relevant to matters in which NSAC may become involved in the future. In addition to collecting the relevant technical information, this requires following the activities of the vendor-oriented owners groups, vendors, and various Atomic Industrial Forum subcommittees, as well as deliberations of NRC and its Advisory Committee on Reactor Safeguards.

▫ NSAC is presently evaluating several of the most critical generic safety issues. The process includes a review of the problem, an evaluation of the work currently being done to achieve resolution of the issue, and identification of additional work that may be needed to achieve resolution. The results of the evaluation are presented in a position paper.

▫ NSAC appoints a matrix manager for the most important problems to ensure a coordinated approach among the various departments of EPRI's Nuclear Power Division. The manager also interfaces with the utilities to ensure technology transfer from pertinent EPRI research programs to utilities that wish to apply the technology in their plants. In addition, NSAC identifies the organization or organizations that are best qualified to perform the needed work. Examples of these organizations are the owners groups, EPRI's R&D departments, NRC, DOE, and NSAC itself. Efforts on NSAC's part normally involve using state-of-the-art technology for performing analyses that might help clarify or resolve the issue. Recommendations for R&D that might be done outside EPRI are coordinated with the appropriate departments within EPRI.

The nuclear industry has been aware of some of the potential generic safety problems for some time, and in many cases there is work under way within EPRI's Nuclear Power Division. As part of the evaluation process, or in the preparation of position papers, NSAC coordinates the relevant R&D effort at EPRI to ensure that all work is fully integrated. The R&D project manager assists the generic safety matrix manager in interpreting the R&D results. In turn, the matrix manager keeps the R&D project managers current on the overall effort so that the R&D program can be modified where appropriate.

NSAC's Generic Safety Analysis Program comprises two areas—current concerns and potential issues. Current concerns include reactor vessel pressurized thermal shock, steam generator tube integrity, shutdown heat removal systems, emergency planning for realistic accident sequences, anticipated transients without scram, near-term regulatory requirement prioritization, and siting criteria.

The second evaluation area, potential issues, includes equipment qualification, single-failure criteria, and reliability of vital (safety and nonsafety grade) equipment.

As an example of how generic issues are being handled, NSAC has assigned the highest priority to work on the safety concerns of reactor vessel pressurized thermal shock. Figure 1 indicates how the work done by different departments is integrated into a cohesive program, which is then transferred to the utility industry.

The long-term cumulative effects of neutron embrittlement of reactor vessel materials have been recognized for more than 25 years. Some of the earliest research work initiated after the establishment of EPRI was in the area of reactor vessel integrity and neutron-induced embrittlement of materials. More recently it has appeared that the materials disciplines alone may not be able to guarantee the integrity of reactor vessels over a 40-year life if simplified calculations and worst-case assumptions are selected.

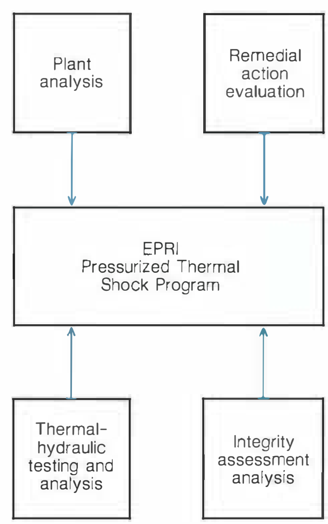


Figure 1 Problems of safety during reactor vessel pressurized thermal shock are studied by several groups and the conclusions are integrated into EPRI's program.

The emphasis has also changed from performance of these vessels during loss-of-coolant accidents to overcooling transients. Such transients can occur from a variety of causes, including reactor coolant system breaks, steam system breaks, or excessive feedwater flow. In June 1981 EPRI expanded and accelerated some programs that are key to the understanding of thermal mixing of reactor coolant system fluids and the resultant three-dimensional temperature patterns along the reactor vessel wall. Although not yet conclusive, early experiments indicate an adequate mixing of cold injection water and reactor water. This knowledge is helping to improve the accuracy of mixing codes. Large-scale experiments will continue over a period of years.

To transfer this package of thermohydraulics, physics, and structural technology to the industry, EPRI has established cooperative programs with four utilities to address reactor vessel pressurized thermal shock concerns at four specific reactor plants, including one from each of the PWR vendors. The evidence suggests that this program will demonstrate that with reasonable assumptions and best-estimate calculations, the safety of reactor vessels can be assured over a 40-year life.

IDENTIFICATION OF COBALT SOURCES

Minimization of the radiation exposure of nuclear plant workers is a goal of the U.S. electric power industry. EPRI's approach to the problem has been directed at controlling the exposure source, the radiation fields associated with out-of-core surfaces. Work has centered on understanding activity transport/buildup mechanisms, and considerable effort has been made to identify effective plant radiation control practices.

A major task in evaluating radiation field buildup in U.S. light water reactors (LWRs) was the development of a consistent data base of reference out-of-core surfaces. Radiation field surveys and isotopic measurements at nuclear power plants have proved to be the cornerstone of the assessment program. Surveillance has been maintained over a large number of operating boiling water reactors (BWRs) and pressurized water reactors (PWRs) that represent a variety of plant design features. This information has allowed for the assessment of operational procedures and plant design features with respect to radiation buildup.

Cobalt-60 has been shown to be the principal contributor to shutdown radiation fields in both BWR and PWR plants. Cobalt is present in nuclear systems as a low-level impurity in the materials used in construction (0.002–0.2%) and as a wear-resistant alloy (50%). These materials wear and corrode; in the process, elemental cobalt is released to the coolant. This material can deposit on the fuel surfaces and become activated to cobalt-60 by the neutron flux. Subsequent release of these fuel deposits results in transport of the radioactive material to the out-of-core surfaces.

Many aspects of the transport/buildup mechanisms remain matters of hypotheses. However, it is clear that cobalt-60 is the dominant long-term contributor to primary system radiation levels and its fundamental source is the elemental cobalt of the structural materials. As a starting point in cobalt minimization efforts, EPRI has attempted to identify the significant cobalt contributors through an engineering review of the materials of construction.

Each system with a coolant pathway to the reactor was individually analyzed for alloys of construction and associate surface area. Information was gathered from a wide range of sources, including suppliers' records, specifications, vendor drawings, and plant as-built drawings. Where information was not available, estimates were based on engineering judgment. This resulted in a material inventory by specification number, cobalt wt%, material-exposed surface area, and coolant conditions. Using this inventory, an analysis was made of the cobalt contribution (g/yr) from the various sources. Engineering judgment played an impoıtant role in this evaluation because only limited data are available on several key parameters (e.g., corrosion release rates, preferential release, and the contribution of wear).

BWR cobalt sources

The assessment of BWR cobalt sources was conducted by General Electric Co. (RP1784-2). Two BWR plants were selected for evaluation. One was Brunswick-2, owned and operated by Carolina Power & Light Co., a BWR/4 of 2436-MW (th) capacity. Brunswick-2 was the host for an earlier detailed water quality surveillance program that provided an extensive data base for comparison with the findings of this study. The second unit was a General Electric Co. BWR/6 of 3579-MW (th) capacity, presently under construction. Both plants have a forward-pumped heater drain system and a dual condensate demineralizer system consisting of filter demineralizers followed by deep-bed demineralizers.

The BWR systems were subdivided into

Table 1
BWR SYSTEMS, MATERIALS, AND COBALT RELEASE ESTIMATES

	Surface Area (dm^2)				Estimated
	Carbon Steel	Stainless Steel	Ni-Cr-Fe	Cobalt-Based Alloys	Cobalt Release (g/yr)
Reactor vessel and internals	5,000	983,000	28,000	285	56.4
Recirculation system	—	21,000	—	98	18.0
Control rod drives	—	101,000	38,000	103	6.0
Reheat steam system	1,618,000	148,000	—	469	141.6
Low-pressure turbine and heater drains	105,000	675,000	—	6	1.2
Main condenser	525,000	5,451,000*	—	—	—
Condensate system to No. 3 heater	168,000	756,000	—	42	7.2
Main steam and high-pressure heater drains	1,002,000	2,280,000	—	375	124.8
High-pressure feedwater system	74,000	780,000	—	84	15.6

Note: This analysis is based on Carolina Power & Light Co.'s Brunswick-2 reactor, a 2436-MW (th) BWR/4.

*Condenser tubes 90-10 Cu-Ni.

the nuclear steam supply systems (NSSS) and the balance of plant (BOP) systems. A wide variety of materials were found to be used in the systems reviewed. However, from a corrosion viewpoint, the number can be reduced to five basic types without compromising the study. These are carbon steel, stainless steel, Ni-Cr-Fe (Inconel 600 and X750), cobalt-based alloys, and copper-nickel alloy. Environmental conditions considered in the analysis were phase (steam and/or water), temperature, conductivity, pH, dissolved oxygen, and coolant velocity. Because of the scarcity of data, considerable engineering judgment was used in selecting appropriate corrosion release rates for the individual systems and components. Here the chemistry data base established at the Brunswick plant proved to be invaluable, as it provided a means of validating the corrosion release rates selected and, in some cases, showed where major adjustments were required.

Table 1 summarizes data generated for the BWR/4 plant. The analysis concludes that 65% of the total cobalt originates from the BOP systems, and 35% from the NSSS portion of the plant. Even more startling, although cobalt-based alloys are less than 0.1% of the plant's surface area, they probably contribute up to approximately 90% of the cobalt input. So cobalt-based alloys appear to be the dominant source of cobalt. A major percentage of these alloys is found as valve trim within the systems studied.

PWR cobalt sources

The evaluation of PWR cobalt sources was conducted by Combustion Engineering, Inc. (RP1784-1) and Westinghouse Electric Corp. (RP1784-3). The C–E analysis used a two-loop, 2560-MW (th) reactor of C–E design for the reference plant. Westinghouse used two plants of different designs as references: a three-loop, 2660-MW (th) plant and a four-loop, 3423-MW (th) plant. These designs are typical of a large segment of the operating BWRs and key reference data were available. As with the BWR study, only systems and components with corrosion product pathways to the reactor water were considered. The analyses were organized into four systems. Because much of the work involved assessments of the primary system, a significant amount of material certification data was available for the analysis. As with the BWR work, numerous assumptions had to be made in estimating the release of cobalt.

Table 2 presents the results derived from the C–E analysis. In general, there is agreement in the results of the two studies. However, one major difference involved the cobalt input from the control rod drive mechanisms (CRDMs). Westinghouse bases its estimate of 3–7 g/yr on prototype testing data. C–E's estimate of 63.9 g/yr is based on corrosion and wear release estimates. Both organizations see the CRDMs as a significant source, although the exact magnitude of the input is yet to be resolved. By this assessment, Inconel steam generator tubing is the principal source of cobalt to the PWR system.

Component wear measurements

Based on a material inventory and assumed cobalt release mechanisms, the significant potential cobalt sources were identified in the work under RP1784. To reduce the uncertainty of the analysis, field measurements of component wear and corrosion losses were performed by Battelle, Columbus Laboratories (RP1567).

Most of the components of interest are large, difficult to remove for examination, contaminated, and without prewear dimension or weight measurement data for comparison with similar postwear measurements. Therefore, the approach taken was to determine by profile measurements the extent of wear relative to nearby unworn surfaces, which were used as references. If components did not lend themselves to direct profilometer measurements (as is normally the case), the measurements were made on plastic replicas of the wear area.

Using the replication and profilometer approach, field measurements were made on a PWR main coolant pump, two BWR feedwater regulator valves, and a BWR reactor cleanup discharge isolation valve. A hardfaced journal on the main coolant pump released the smallest quantity of cobalt, estimated to be approximately 0.04 g/yr. Measurements indicated that the two feedwater regulator valves released 20 g/yr and 8 g/yr, respectively, and the cleanup discharge isolation valve released 2 g/yr. These three valves were from the same plant and represent an input of approximately 30 g/yr of cobalt. Based on the findings of this work, efforts were made by the utility to reduce these sources by applying cobalt-free stainless steel for the feedwater regulator valve components and effecting an operational change to lower the wear of the

Table 2
PWR SYSTEMS, MATERIALS, AND COBALT RELEASE ESTIMATES

	Inconel		Stainless Steel		Cobalt-Based Alloys		Total Estimated Cobalt Release (g/yr)
	Surface Area (dm²)	Cobalt Release (g/yr)	Surface Area (dm²)	Cobalt Release (g/yr)	Surface Area (dm²)	Cobalt Release (g/yr)	
Reactor coolant system*	1,520,000	32.8	179,000	3.7	684	63.9	100.4
Chemical and volume control system	—	—	21,000	0.7	41	1.7	2.4
Boric acid system	—	—	21,000	0.6	22	0.9	1.5
Shutdown cooling system	—	—	111,000	0.5	57	0.6	1.1

Note: This analysis is based on a two-loop, 2560-MW (th) PWR of Combustion Engineering, Inc., design.

*This system also contains Zircaloy (surface area 597,000 dm²).

Figure 2 Worn surface of a BWR feedwater regulator.

cleanup discharge isolation valve. Figure 2 shows a portion of the worn area of one BWR feedwater regulator valve.

Corrosion product cobalt release rates

EPRI recently initiated a project to determine the release rates of elemental cobalt from the principal nuclear plant materials of construction (RP2008). Atomic Energy of Canada, Ltd., will undertake this investigation, using a test loop at the Chalk River Nuclear Laboratories. Ion implantation techniques will be applied in determining corrosion mechanisms and release kinetics. Also, the effects of surface prefilming, oxidation, and corrosion deposition on cobalt release rates will be investigated. Initially, the testing will involve four basic materials—Inconel 600, Zircaloy 4, 304 stainless steel, and a high-cobalt alloy—at PWR chemistry conditions. Later in the project, BWR construction materials will be evaluated in a similar manner.

EPRI's effort to date in quantifying the sources of cobalt in LWRs must be viewed as a first assessment. Numerous assumptions were made and many of them significantly shaped the final conclusions. The uncertainty of this analysis will diminish as additional wear measurement data and corrosion release information become available. *Project Manager: Michael Naughton*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1654-11	Fundamental Analysis of Ash Deposition Mechanisms in Entrained Slagging Gasifiers	1 year	60.0	Pennsylvania State University *T. O'Shea*
RP2029-8	Thermodynamic Analysis of Energy Conversion Processes	15 months	72.7	Desert Research Institute *M. Gluckman*
RP2106-1	Synfuels Utilization Guidebook for Electric Utility Combustion Systems	20 months	331.4	KVB, Inc. *W. Rovesti*
RP2147-1	Role and Origin of Active Solvents for Coal Liquefaction	4 months	30.0	Battelle, Pacific Northwest Laboratories *L. Atherton*
RP2147-3	Coal Liquefaction Studies	10 months	220.0	University of Wyoming *N. Stewart*
RP2196-1	Workshop: Solar-Thermal Technology Evaluation and Program Plan Development	4 months	69.5	Westinghouse Electric Corp. *J. Bigger*
RP2207-1	Advanced Fossil Fuel Technologies for Electric Power Systems: A Guide to Technical Status, Economics, and Applications	3 months	200.0	Synthetic Fuels Associates, Inc. *M. Gluckman*
Coal Combustion Systems				
RP734-4	Diagnostic Monitoring of Axial Draft Fan Bearings	22 months	176.7	Battelle Memorial Institute *A. Armor*
RP734-5	Acoustic Emission Monitoring of Steam Turbines	2 years	230.0	Rockwell International Corp. *A. Armor*
RP1260-20	Evaluation of the Potential of Nonmetallic Heat Exchangers for Dry Cooling	13 months	99.7	Dynatech R/D Co. *J. Bartz*
RP1261-90	Combined Makeup and Sidestream Hybrid Treatment Testing	4 months	53.0	Public Service Co. of Colorado *W. Chow*
RP1840-3	Coal Cleaning by Oil Agglomeration With Oil Recovery	20 months	168.2	Ontario Hydro *F. Karlson*
RP1870-3	Spray-Dry FGD Pilot Plant Evaluation and Data Collection	18 months	898.8	Radian Corp. *R. Rhudy*
RP1887-1	Recommended Design and Procurement Guidelines for Feedwater Heaters in Large Power-Generating Plants	20 months	152.0	Joseph Oat Corp. *I. Diaz Tous*
RP1895-5	Coal-Oil Mixture Test	7 months	93.0	Florida Power & Light Co. *R. Manfred*
Electrical Systems				
RP796-2	Field Evaluation of Composite Wood Crossarms	70 months	149.8	Michigan Technological University *R. Tackaberry*
RP1915-1	Considerations in Developing and Utilizing System Operation Training Simulators	18 months	249.8	Electrocon International, Inc. *C. Frank*
RP2080-1	Double Circuit Line Design	8 months	55.4	General Electric Co. *J. Dunlap*
RP7810-90	Waltz Mill Underground Cable Test Facility	9 months	1920.0	Empire State Electric Energy Research Corp. *J. Shimshock*
Energy Analysis and Environment				
RP1152-7	National Electric Issues Decision Framework	10 months	30.1	Applied Decision Analysis, Inc. *H. Chao*
RP1487-12	Physical-Chemical Composition of Electric Utility Solid Wastes	9 months	125.4	TetraTech, Inc. *I. Murarka*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1619-1	Geohydrochemical Models for Contaminants—An Initial Evaluation	10 months	271.8	Battelle, Pacific Northwest Laboratories *I. Murarka*
RP1916-4	Forecasting Total Energy Demand by Sector and by State	1 year	50.0	Ecometrix, Ltd. *L. Williams*
RP1981-7	Natural Gas and the Electric Utilities: Phase 1, Gas Supply and Utilization Outlook for R&D Planning	5 months	50.0	Charles River Associates, Inc. *J. Platt*
RP2043-1	Response of Industrial and Commercial Customers to Time-of-Use Prices	18 months	300.0	Research Triangle Institute *A. Faruqui*
RP2071-1	Materials Damage From Acid Deposition	1 year	131.0	Rockwell International Corp. *R. Wyzga*
RP2074-1	Use of Existing Facilities in Electricity Supply Planning	1 year	249.6	Temple, Barker, & Sloane, Inc. *D. Geraghty*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1198-15	Posttest Examination of Beta (Na-S) Cells	1 year	100.0	Argonne National Laboratory *R. Weaver*
RP1275-12	Feasibility Assessment: Customer Side of the Meter Applications for Battery Energy Storage	4 months	61.7	Bechtel Group, Inc. *D. Douglas*
RP1745-6	Cost and Design Study: Prefabricated Small Hydro	11 months	222.8	Acres American, Inc. *C. Sullivan*
RP2033-8	Examination of Nonazeotropic Mixture Refrigerants for Heat Pumps	20 months	198.1	National Bureau of Standards *J. Calm*
RP2033-9	Monitoring of Central and Room Heat Pumps	19 months	249.6	Carrier Corp. *J. Calm*
RP2192-1	Air-Cooled Fuel Cell Power Plant Definition	44 months	1400.0	Westinghouse Electric Corp. *D. Rastler*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP623-5	High-Temperature Aqueous Sulfate Systems	11 months	99.1	Union Carbide Corp. *J. Paine*
RP1167-8	Surface Oxide Films in Relation to Localized Corrosion	23 months	98.0	Brookhaven National Laboratory *D. Cubicciotti*
RP1377-5	Adjacent Surface Interaction in BWR Bundle Heat Transfer	19 months	39.1	University of California at Berkeley *M. Merilo*
RP1761-9	Simulation of Flow in BWR Methodology	1 year	98.0	Science Applications, Inc. *J. Naser*
RP2006-1	Prediction of Environmental Crack Growth in Nuclear Power Plant Components	30 months	955.6	Westinghouse Electric Corp. *J. Gilman*
RP2011-1	Development of an Alarm System Improvement Guide	16 months	164.6	McDonnell Douglas Astronautics Co. *J. O'Brien*
RP2011-2	Analysis of Nuclear Power Plant Alarms	16 months	70.0	MPR Associates, Inc. *J. O'Brien*
RP2012-2	Evaluation of Nonchemical Decontamination Techniques for Use on Selected TMI-2 Reactor Coolant Systems	5 months	155.2	Quadrex Corp. *M. Naughton*
RP2012-4	TMI-2 Decontamination Methodology Study	6 months	67.4	Westinghouse Electric Corp. *L. Anderson*
RP2061-6	Development of Functional Specifications for Licensing Aspects of SPEAR FCODE GAMMA	6 months	74.2	Combustion Engineering, Inc. *T. Oldberg*
RP2073-1	Main Steam Line Plug for BWR Application	4 months	222.3	Preferred Engineering Corp. *B. Brooks*
RP2122-1	Three-Dimensional Analysis for Thermal and Fluid Mixing During High-Pressure Coolant Injection Using COMMIX-1A	15 months	130.0	Argonne National Laboratory *J. Kim*
RP2124-1	Hydrodynamic Damping of Fuel Assemblies	3 months	49.2	Joseph Oat Corp. *N. Hirota*
RP2125-1	Ice Condenser Sublimation Control	6 months	97.5	Westinghouse Electric Corp. *N. Hirota*
RP2172-1	Methods for Ultimate Load Analysis of Concrete Containment	11 months	101.3	Anatech International Corp. *Y. Tang*

R&D Staff

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1885-1	Analysis of ASME Task Group Questionnaire on Solid Particle Erosion	4 months	30.0	Wood-Leaver and Associates, Inc. *J. Stringer*

New Technical Reports

Each issue of the *Journal* includes summaries of EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

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ADVANCED POWER SYSTEMS

Coal Gasification Environmental Baseline Studies

AP-2215 Final Report (RP985-1); $12.00

Baseline studies to determine the environmental acceptability of the Texaco coal gasification process are summarized. Tests on oxygen and enriched-air gasification of a water slurry of Illinois No. 6 coal are described. Analyses of various solid, liquid, and gaseous effluent streams sampled during steady-state operation are reviewed, and the results compared against relevant Resource Conservation and Recovery Act criteria and proposed California standards. The contractor is Texaco, Inc. *EPRI Project Manager: John McDaniel*

Rock-Brine Chemical Interactions

AP-2258 Final Report (RP653-2); $10.50

Laboratory experiments were conducted to study the interaction of powdered volcanic rock with aqueous solutions at temperatures of 200–400°C and fluid pressures of 500–1000 bars; reaction durations were approximately 30 days. Data on the kinetics and equilibria of rock-solution interactions are presented that provide insight into complex geothermal processes attending geothermal reservoir development, stimulation, and reinjection. The contractor is Stanford University. *EPRI Project Manager: M. J. Angwin*

Evaluation of Biomass Systems for Electricity Generation

AP-2265 Final Report (RP1348-7); $15.00

The state of the art of alternative biomass systems for electricity generation was assessed. The study considered biomass resources (silvicultural and agricultural), biomass conversion to fuels, and the end uses of these fuels for electricity generation. It also identified current and future opportunities for, and constraints on, biomass utilization by electric utilities. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: S. M. Kohan*

Thermal and Mechanical Stresses in the Ceramic Seal of 1-MW (th) Bench-Model Solar Receiver

AP-2267 Final Report (RP475-9); $16.50

This report presents an analytic and experimental assessment of the thermal-mechanical stress levels associated with the high-temperature tube-manifold ceramic joint for a 1-MW (th) bench-model solar receiver. Details are provided on appropriate design and material changes for this joint to provide an acceptably low probability of failure. The contractor is AiResearch Manufacturing Co. *EPRI Project Manager: W. T. Bakker*

Electric Utility Use of Coal-Derived Fuels: Health, Personnel Protection, and Regulatory Considerations

AP-2288 Final Report (RP1735-1); $13.50

Potential health problems associated with occupational exposure during the use or transportation of coal-derived liquid fuels were investigated. This report summarizes a review of literature on the health and environmental effects of these fuels, surveys applicable legislation and regulations, and describes measures designed to minimize or eliminate any known hazards. The contractors are Gulf Mineral Resources Co. and Tabershaw Occupational Medicine Associates. *EPRI Project Manager: Walter Weyzen*

Fusion Reactor Control Study

AP-2293 Summary and Final Reports (RP546-2, -3); Vol. 1, $9.00; Vol. 2, $27.00; Vol. 3, $15.00; Vol. 4, $7.50

This report describes the first study of the control requirements of the leading magnetic and inertial confinement fusion reactor concepts. Volume 1 is a summary document. Volume 2 describes control and instrumentation requirements of a tokamak experimental power reactor concept; Volume 3, the control requirements of the tandem mirror reactor concept; and Volume 4, the control requirements of inertial confinement fusion reactor concepts. The contractor is The Charles Stark Draper Laboratory, Inc. *EPRI Project Manager: N. A. Amherd*

Small-System Generation Requirements: Fuels and Technologies

AP-2320 Final Report (TPS80-718); $13.50

The results of a survey of a selected group of small municipal, cooperative, and private utilities are presented. The objective was to determine the resources, technologies, and sizes of installations preferred by small utilities and the utilities' willingness to convert existing power plants to synthetic liquid or gaseous fuels. To assess regional differences, responses were grouped into five regions, approximating the National Electric Reliability Council areas. The contractor is SAI Engineers, Inc. *EPRI Project Manager: S. M. Kohan*

COAL COMBUSTION SYSTEMS

Review of Thawtron Device for Thawing Frozen Coal

CS-2253 Final Report (RP1266-25); $12.00

This report discusses the use of microwave energy to thaw frozen coal and assesses one device proposed for this purpose, the Thawtron device. The microwave and thermal properties of coal and other materials are reviewed, and microwave thawing is compared with mechanical devices, radiant heaters, and freeze conditioning agents as an aid in unloading railroad cars filled with frozen coal. The contractor is SRI International. *EPRI Project Manager: I. A. Diaz-Tous*

Evaluation of Energy Recovery From Municipal Solid Waste in Oil-Fired Power Plants

CS-2274 Final Report (RP1255-90); $13.50

Five methods of energy recovery from municipal solid waste (MSW) in oil-fired power plants are evaluated: preparation and supplemental firing of refuse-derived fuel (RDF) with oil in a utility boiler originally designed for coal firing; 100% firing of either RDF or MSW in a dedicated water-wall incinerator and use of the steam to drive a dedicated turbine generator unit; and 100% firing of RDF or MSW in a dedicated water-wall incinerator and integration of the steam into the power plant steam cycle. The contractor is Stone & Webster Management Consultants, Inc. *EPRI Project Manager: C. R. McGowin*

Preliminary Assessment of Alternative AFBC Power Plant Systems

CS-2275 Final Report (RP1179-7); $22.50

An evaluation of alternative methods of reducing limestone consumption in atmospheric fluidized-bed combustion (AFBC) boilers is presented. Four methods were considered: inert fluidized beds with wet or dry flue gas desulfurization systems; precalcination of limestone; regeneration of spent limestone; and agglomeration and recycle of spent limestone. A sensitivity analysis was performed to simulate the cost and performance of the current AFBC-recycle boiler design. The contractor is Burns and Roe, Inc. *EPRI Project Manager: C. R. McGowin*

Design and Operating Guidelines Manual for Cooling-Water Treatment

CS-2276 Final Report (RP1261-1); $31.50

This preliminary manual was developed to provide a systematic procedure for evaluating candidate strategies for the treatment of recirculated cooling water. It presents (1) a means of selecting optimal treatment methods and facilities on the basis of technical and economic considerations, and (2) guidelines for proper cooling-water system operation. Descriptions of, and user's manuals for, the cooling-system process and chemical equilibrium computer simulation models are included. The contractors are Stearns-Roger Engineering Corp. and Radian Corp. *EPRI Project Managers: Winston Chow and R. M. Jorden*

Wear of Steam Turbine Journal Bearings at Low Operating Speeds

CS-2281 Interim Report (RP1648-3); $10.50

This report presents the Phase 1 results of a project to determine the parameters governing the wear of steam turbine generator journal bearings during low-speed operation. Information collected from interviews and site visits is reviewed, and an analysis of the effect of bearing wear on lubrication at low operating speeds is presented. The possibility of the existence of an optimal level of wear for the generation of hydrodynamic oil films at low speeds is examined. The contractor is Battelle, Columbus Laboratories. *EPRI Project Managers: T. H. McCloskey and J. B. Parkes*

Combustion Tests of Coal-Water Slurry

CS-2286 Final Report (RP1895-2); $9.00

An experimental test program was conducted to determine the combustion characteristics of a coal-water slurry fired with existing fuel-handling equipment. Test results for both the slurry and the parent coal are presented, along with details on fuel and ash analyses. Fuel viscosity characteristics, particle size distribution, and moisture content are also discussed. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: R. K. Manfred*

Coal-Water Slurry as Utility Boiler Fuel

CS-2287 Final Report (RP1180-12, RP1895-1); $10.50

This report describes an investigation of the formulation, processing, handling, combustion, and storage properties of coal-water slurries (CWS) using cleaned coal (reduced sulfur and ash content). A preliminary design for a CWS production plant was developed, along with capital and operating cost estimates. The project illuminated some of the physical properties that are important in considering a feed coal for slurry production. The contractor is Atlantic Research Corp. *EPRI Project Manager: R. K. Manfred*

Test Plan for AFBC Control System Development at TVA's 20-MW (e) Pilot Plant

CS-2308 Final Report (RP1179-10); $9.00

The tests required to evaluate the dynamic response characteristics of the Tennessee Valley Authority's 20-MW (e) atmospheric fluidized-bed combustion pilot plant are described. The report discusses the relationship of dynamic modeling to the test program and the use of test results in an analytic approach to control design. The transient test procedures, instrumentation, and data acquisition requirements are described. The contractor is Jaycor. *EPRI Project Manager: W. C. Howe*

Feed Pump Hydraulic Performance and Design Improvement

CS-2322 Final Report (RP1884-5); Vol. 1, $13.50; Vol. 2, $15.00

This project on feedwater pump hydraulic performance and design is part of an effort to improve the reliability of feed pumps for large power-generating units. Volume 1 details the results of a study to plan a coordinated approach to reduce boiler feed pump problems. Volume 2 presents a survey of six boiler feed pump manufacturers, abstracts of important references obtained from a literature survey, and a discussion of feed pump problems and current pump hydraulic flow theory. The contractors are Franklin Research Center and Transamerica Delaval, Inc. *EPRI Project Manager: I. A. Diaz-Tous*

Feed Pump Hydraulic Performance and Design Improvement, Phase 1: Research Program Design

CS-2323 Final Report (RP1884-6); Vol. 1, $15.00; Vol. 2, $18.00

This report contains a research plan to provide an improved basis for the design, procurement, testing, and operation of large feed pumps with increased reliability and stability over a full range of operating conditions. Volume 1 outlines and updates feed pump procurement and design methods, problems, research, and theory; it also estimates the benefits and costs of the R&D program. Volume 2 contains detailed appendixes. The contractors are Borg-Warner Corp. and the Massachusetts Institute of Technology. *EPRI Project Manager: I. A. Diaz-Tous*

Evaluation of Models for Predicting Evaporative Water Loss in Cooling Impoundments

CS-2325 Interim Report (RP1260-17); $16.50

Evaporation is examined from both a theoretical and an empirical perspective. The performance of several commonly employed evaporation equations is compared by using two comprehensive data sets and a dynamic cooling pond model. The effect of averaging meteorologic input data is explored, and an extension of the Harbeck diagram is presented to account for nonlinearities in the estimation of forced evaporation. The contractor is the Massachusetts Institute of Technology. *EPRI Project Manager: J. A. Bartz*

ELECTRICAL SYSTEMS

Field Demonstrations of Communication Systems for Distribution Automation: Program Report

EL-1860 Final Report, Vol. 1 (RP850); $15.00

This report summarizes the results of an investigation to develop and test communication systems for distribution automation and load management. The program consisted of three power line carrier projects, a UHF radio project, and a telephone project. For each project a two-way (half-duplex) digital communication system was developed to perform such functions as fault location and isolation, distribution feeder switching, load control, time-of-day metering, remote meter reading, and equipment monitoring. The contractor is V. T. Rhyne. *EPRI Project Manager: W. E. Blair*

Lightning Research Plan

EL-2289 Final Report (RP1980-1); $13.50

A comprehensive, coordinated plan for undertaking future lightning research is presented. The report reviews lightning research and includes a bibliography of relevant literature published in the last 10 years. A broad range of topics is covered, from gathering data on the statistical distribution of lightning characteristics to the preparation of a design guide for lightning protection engineers. The contractor is Ebasco Services Inc. *EPRI Project Manager: H. J. Songster*

Evaluation of Electrical Interference to the Induction Watthour Meter

EL-2315 Final Report (RP1738); $19.50

Results are presented from a series of tests on various commercially available self-contained induction watthour meters. The meters were exposed to electrical interference typical of the application environment (harmonic frequencies, transient surges, distortion of current waveform, and electrical noise), and the effects on accuracy were recorded. The meters registered within ± 4% under all test conditions except in a few cases with severely distorted loads. The contractor is Honeywell, Inc. *EPRI Project Manager: W. E. Blair*

Evaluation of the NGH Subsynchronous Resonance Damping Scheme

EL-2327 Final Report (RP1504-1); $10.50

This report presents the results of an analytic investigation of the NGH scheme, a method of damping subsynchronous resonance (SSR). The scheme is designed to solve the two major types of SSR—transient torque and steady-state resonance. The Coronado 456-MW generator of the Salt River Project and the cross-compound 483-MW and 426-MW Mojave generators of Southern California Edison Co. provided two applications for study by means of detailed computer simulations. The contractor is Siemens-Allis, Inc. *EPRI Project Manager: N. G. Hingorani*

Feasibility of Using Associative Memories for Static Security Assessment of Power System Overloads

EL-2343 Final Report (RP1047-2); $12.00

This report explores the feasibility of applying pattern recognition methods to the task of static security assessment. Two methods, associative memory pattern recognition and rule-based (or rule-directed) associative memory pattern recognition, were investigated by using a computer model of an actual transmission network comprising 196 buses at 328 branches. The contractor is Case Western Reserve University. EPRI Project Manager: C. J. Frank

ENERGY ANALYSIS AND ENVIRONMENT

Modeling Water Supply for the Energy Sector

EA-2330 Final Report (RP662); $18.00

This report describes the integration of water constraints into an existing energy model (in terms of water supply curves and demand detail) and the subsequent testing of this water-energy model with hypothetical energy scenarios. The contractor is Stanford University. *EPRI Project Manager: Dominic Geraghty*

Proceedings: Ecological Effects of Acid Precipication

EA-2273 Proceedings (WS80-180); $12.00

This report contains the proceedings of an EPRI–EPA workshop on the ecological effects of acid precipitation that was held in March 1981 in Atlanta, Georgia. Participants from the United States, Canada, Norway, Sweden, and the United Kingdom exchanged information on the emphases, approaches, techniques, and planned directions of their countries' acid precipitation programs. Possible methods of coordinating these programs were discussed, and further research needs were defined. The contractor is Sigma Research, Inc. *EPRI Project Manager: R. A. Goldstein*

Feasibility of Large-Scale Aquatic Microcosms

EA-2283 Final Report (RP1224-6); $18.00

The applicability of large-scale freshwater microcosms to utility industry ecological assessment problems was evaluated on the basis of information collected from research site visits and a literature review. Large-scale microcosm designs are reviewed, a general engineering design for a lake-simulating microcosm is described, and the design criteria and costs for such a simulation facility are discussed. The contractor is Lawler, Matusky & Skelly Engineers. *EPRI Project Manager: Robert Kawaratani*

Environmental Studies Data Base Feasibility Project

EA-2311 Final Report (RP1489); $13.50

This project was initiated to determine the feasibility of developing a computerized system for use in the storage, retrieval, and analysis of aquatic environmental data related to electric power plants. The feasibility of integrating existing environmental data from site-specific power plant studies and other sources into a unified structure was investigated, and a pilot-scale data base system was designed and tested. The contractors are Ecological Analysts, Inc., and Sigma Data Computing Corp. *EPRI Project Manager: I. P. Murarka*

Transportation Network Models for Energy Supply Analysis

EA-2324 Final Report (RP1219-3); 5 vols. (priced per vol.)

Future coal transportation costs and capacities were examined by using a national multimodal transportation network model. The model is designed to forecast energy transportation system performance and the effects of technology and network structural changes. Volume 1 is an executive summary. Volume 2 describes the methodology used and presents the results of an analysis of three scenarios. Volume 3 presents a user's guide and complete model documentation. Volume 4 presents the model's support programs, and Volume 5 contains appendixes. The contractor is C.A.C.I., Inc.–Federal. *EPRI Project Manager: E. G. Altouney*

Demand for Energy in the Commercial Sector

EA-2330 Final Report (RP662); $18.00

This report describes the development of an aggregate econometric forecasting model of energy use by the commercial sector. The model estimates demand for electricity, natural gas, and fuel oil. It is aggregate in that it does not differentiate between business types or end uses within the commercial sector. Issues addressed in the project included the development of energy consumption data consistent with an economic definition of the commercial sector, and the estimation of the stock of commercial floor space and additions to it. The contractor is Data Resources, Inc. *EPRI Project Manager: J. B. Wharton*

ENERGY MANAGEMENT AND UTILIZATION

Preliminary Design Study of Compressed-Air Energy Storage in a Salt Dome

EM-2210 Final Report (RP1081-2); 7 vols. (priced per vol.)

This report describes a project to determine design criteria and develop preliminary engineering designs for a compressed-air energy storage (CAES) concept. Volume 1, an executive summary, presents the preliminary design and cost estimates. Volume 2 covers the facility design criteria; Volume 3, construction of a CAES cavern; Volume 4 (forthcoming), CAES turbomachinery design; Volume 5, the system, subsystems, and components required to meet the facility design criteria; Volume 6, preliminary plant design; and Volume 7, environmental and safety considerations. The contractors are United Engineers & Constructors, Inc., and Middle South Services, Inc. *EPRI Project Manager: Antonio Ferreira*

Geotechnical Basis for Underground Energy Storage in Hard Rock

EM-2260 Final Report (RP1199-11); $30.00

This study established an extensive data base that underscores the practicality of using state-of-the-art underground reservoir construction and engineering methods for compressed-air storage and underground pumped-hydro storage facilities. Successful worldwide applications of rock mechanics in opening up underground space show that large caverns constructed for energy storage, as well as the connecting shafts and tunnels, can be expected to operate without maintenance on a near-permanent basis. The contractor is O. C. Farquhar. *EPRI Project Manager: Antonio Ferreira*

Assessment of Coal Gasification–Fuel Cell System for Utility Application

EM-2387 Final Report (RP1041-8); $15.00

This scoping study defines, and assesses the technical and economic feasibility of, a coal gasification–advanced phosphoric acid fuel cell power plant for electric utility application. The selected system design criteria resulted in a modular, relatively small power plant that could be configured with a basic building block of approximately 11 MW. The contractor is Kinetics Technology International Corp. *EPRI Project Manager: B. R. Mehta*

NUCLEAR POWER

BWR Small-Break Simulation Tests With and Without Degraded ECC Systems

NP-1782 Interim Report (RP495-1); $21.00

Simulation tests of BWR small-break loss-of-coolant accidents were conducted in a two-loop apparatus to investigate the small break (1) with nondegraded emergency core coolant (ECC) systems, and (2) with degraded ECC systems in which the high-pressure core spray was assumed to be unavailable. The test apparatus, instrumentation, measurements, and results are summarized. The contractor is General Electric Co. *EPRI Project Manager: S. P. Kalra*

DUVAL: Computer Program for the Numerical Solution of Two-Dimensional, Two-Phase Flow Problems

NP-2099 Final Report, Vols. 1–3 (RP963-1); $21.00

This report documents the DUVAL computer code, which was developed to simulate the thermal-hydraulic behavior of two-dimensional, thermally expandable flow. It is divided into three volumes, which describe (1) the equations, models, and numerical techniques used in the code; (2) the program specifications, input descriptions, and sample problem results; and (3) the program structure, logic, and detailed solution schemes. The contractor is the University of Pittsburgh. *EPRI Project Manager: P. G. Bailey*

Basic Techniques in Availability Engineering

NP-2166 Final Report (RP1391-2); $16.50

The basic techniques of availability engineering—which are applicable to availability, reliability, maintainability, and decision analysis—are reviewed, and examples of data analysis and decision processes are presented for each element. Use of this report as an engineering reference text in support of EPRI's data usage workshops is described. The contractors are the Southwest Research Institute and The S. M. Stoller Corp. *EPRI Project Manager: J. M. Huzdovich*

Fluid and Thermal Mixing in a Model Cold Leg and Downcomer With Vent Valve Flow

NP-2227 Interim Report (RP347-1); $18.00

This report describes a three-month program of fluid-mixing experiments performed in an atmospheric $\frac{1}{5}$-scale transparent model of the cold leg and downcomer of a PWR with vent valves. Facility geometry, instrumentation, and test operation procedures are described. Data are presented in graphic and tabular form. The contractor is Creare Inc. *EPRI Project Manager: K. H. Sun*

Application of Tearing Modulus Stability Concepts to Nuclear Piping

NP-2261 Final Report (RPT118-9); $13.50

A tearing modulus stability concept (applied earlier only to straight piping runs containing circumferential flaws) was applied to existing nuclear piping in several BWRs and PWRs to determine if guillotine breaks are possible at loads exceeding ASME Code Level D faulted conditions. Results suggest that the austenitic pipe analyzed is fracture-proof, but that all ferritic pipe may not be. The contractor is Fracture Proof Design Corp. *EPRI Project Managers: D. M. Norris, T. U. Marston, and R. L. Jones*

Flooding in Vertical Gas-Liquid Countercurrent Flow Through Parallel Paths

NP-2262 Final Report (RP1160-1); $13.50

This report describes an experimental and analytic study of the basic flow phenomena associated with the onset of flooding. The influence of the number of paths and the paths' spacing is described qualitatively; the validity of a Wallis-Kutateladze type of correlation for multiple-path geometry is confirmed; the influence of geometric factors on the coefficients is given for particular geometries; and a different qualitative analytic approach, resulting in a generalized type of flooding correlation, is presented. The contractor is the University of California at Berkeley. *EPRI Project Manager: Meir Toren*

BWR Cobalt Source Identification
NP-2263 Final Report (RP1784-2); $15.00

A study was undertaken to establish significant sources of cobalt input to reactor water in BWRs. Two BWR plants were used as reference designs. Environmental conditions were defined, and related corrosion and erosion loss rates were developed. Corrosion-product (iron, nickel, and cobalt) inputs to the reactor water from relevant nuclear steam system and balance-of-plant sources were calculated and compared with sample data from an operating BWR. Methods of eliminating or reducing cobalt input were evaluated. The contractor is General Electric Co. *EPRI Project Manager: M. D. Naughton*

Application of 2¼Cr-1Mo as a Structural Material in Saturated-Steam-Cycle LMFBR Systems
NP-2264 Final Report (RP2066-1); $15.00

This report documents an evaluation of the suitability of, and incentives for, using 2¼Cr-1Mo ferritic steel as a structural material for the entire primary and secondary sodium systems in a 1000-MW (e) pool-type LMFBR. Critical properties, design data, and advantages and disadvantages of 2¼Cr-1Mo are identified for each major reactor component. The relative importance of alloy properties to the successful use of ferritics in LMFBRs is described, and potential licensing issues are discussed. The contractor is General Electric Co. *EPRI Project Manager: J. T. A. Roberts*

Secondary Water Chemistry at Ringhals Unit 2
NP-2268 Topical Report (RPS170-1); $9.00

A detailed review of the design characteristics, operating philosophy, and chemical history of Unit 2 of the Swedish State Power Board's Ringhals nuclear station is presented. The report summarizes in-line chemistry instrumentation data and blowdown chemistry specifications for normal operation. It also reviews eddy-current inspections of the steam generators. The contractor is NWT Corp. *EPRI Project Manager: G. W. DeYoung*

Effect of Changing Hydrazine Injection Point at the H. B. Robinson Plant
NP-2270 Final Report (RPS132-2); $9.00

This report describes testing at Unit 2 of Carolina Power & Light Co.'s H. B. Robinson nuclear plant to evaluate the effects of hydrazine injection on condensate and feedwater oxygen concentrations and on corrosion-product transport. The effects on iron, copper, and nickel concentrations in the feedwater, condensate, main steam reheater, and one feed heater are detailed. Plans for future testing are described. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Coit*

Induced-Vibration Analysis Probe for Measuring Steam Generator Tube–Support Plate Clearance
NP-2271 Final Report (RPS102-3); $13.50

This report describes a project to design, fabricate, and evaluate vibration probe hardware for determining the clearance between steam generator tubes and supports. Two vibration probe designs are detailed: one using an externally mounted drive motor and the other using an internal motor. Mockup tests are described, and results and recommendations are presented. The contractor is Anco Engineers, Inc. *EPRI Project Manager: G. W. DeYoung*

Transient Fuel Pin Temperature Calculations Using Describing Functions
NP-2278 Final Report (RP1321-2); $15.00

This report describes an analytically based method to calculate transient temperature profiles with temperature-dependent properties by using generalized transfer functions or describing functions to characterize the system nonlinearities. This study appears to be the first application of describing functions to the solution of partial differential equations. The contractor is Oregon State University. *EPRI Project Manager: R. N. Oehlberg*

Westinghouse FREY Calculations
NP-2279 Final Report (RP1627-4); $10.50

The FREY code, a transient analysis code for fuel rods, was used to evaluate three ANSI Condition II overpower transients: excessive load increase, boron dilution, and rod withdrawal at power. Problem inputs were generated from system models and fuel rod parameters. FREY results were compared with results from a Westinghouse fuel rod modeling code. A complete set of documentation is provided. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. N. Oehlberg*

Liquid Film Fraction and Pressure Drop Characteristics in Vertical Countercurrent Annular Flow
NP-2280 Topical Report (RP443-2); $16.50

This report describes an experimental study of the occurrence and formation of a highly agitated liquid film in a transparent vertical tube with countercurrent annular air-water flow. On the basis of momentum transfer and continuity considerations, an analytic model was developed to calculate the film thickness and pressure drop. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

Pulse-Echo Ultrasound for Steam Generator Tube–Support Plate Gap Measurement
NP-2285 Final Report (RPS142-1); $12.00

An ultrasonic technique was developed for determining the condition of the gap between the outer surface of steam generator tubes and the magnetite corrosion layer on the support plates. This report discusses the identification and resolution of the problems of multiple reverberations in the tube wall and excessive nonspecular sound scattering. It also describes procedures to detect areas of contact between tube and magnetite and to profile the crevice gap. The contractor is Indianapolis Center for Advanced Research, Inc. *EPRI Project Manager: G. W. DeYoung*

Guide to the Design of Secondary Systems and Components to Minimize Oxygen-Induced Corrosion
NP-2294 Final Report (RPS189-1); $18.00

This design guide discusses features that should be specified in PWR components and designed into systems to minimize oxygen-induced corrosion. It covers sources of air inleakage and its reduction, oxygen introduction from condensate storage tanks, the use of chemicals to scavenge oxygen and protect surfaces from oxygen-induced corrosion, the selection of materials resistant to oxygen-induced damage, and methods of removing oxygen from condensate under low-load conditions. The contractor is Bechtel Group, Inc. *EPRI Project Manager: R. L. Coit*

PWR Steam Generator Cost-Benefit Methodology: Denting
NP-2295 Final Report (TPS81-777); $10.50

Cost-benefit methodology was applied to a preliminary model of the steam generator corrosion problem of denting. This report describes the model's major components and demonstrates how cost-benefit analysis can be applied to the various maintenance, repair, and design options for improving the reliability and economic life of PWR steam generators. The contractor is Applied Decision Analysis, Inc. *EPRI Project Manager: J. A. Mundis*

Snubber Reliability Improvement Study
NP-2297 Final Report (RP1388-1); $19.50

Recommendations for snubber design, qualification testing, and acceptance testing are provided, including lockup velocity and acceleration; environmental conditions; and spring rate, release rate, deadband, load level, and related tolerances. The report focuses on two snubber reliability problems: hydraulic fluid leakage and failure of operability tests. Additional recommendations for storage, installation, in-service maintenance and inspection, and remote monitoring are presented. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: J. M. Huzdovich*

Chemistry of Corrosion-Producing Salts in Light Water Reactors
NP-2298 Final Report (RP967-2); $15.00

The results of a project to help solve or prevent corrosion problems in high-temperature LWR systems are summarized. Pourbaix diagrams are presented for $Fe-H_2O$, $Fe-Cl-H_2O$, $S-H_2O$, $Fe-S-Cl-H_2O$, $Ni-H_2O$, $Ni-Cl-H_2O$, $Ni-S-H_2O$, and $Ni-S-Cl-H_2O$ systems at 25, 100, and 200°C. Limitations regarding use are discussed, and several examples of applications are presented. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: T. O. Passell*

Field Experiences With Multifrequency-Multiparameter Eddy-Current Technology
NP-2299 Final Report (RPS115-1); $13.50

This report describes a multifrequency-multiparameter eddy-current system for the in-service inspection of PWR steam generator tubing. The assembled in-containment system and the data analysis system are detailed, and system principles, field experiences, and benefits are discussed. Various mixing approaches for support plate suppression are illustrated, and examples of single and multiple extraneous variable suppression are given. The contractors are Battelle, Columbus Laboratories and EPRI NDE Center (operated by J. A. Jones Applied Research Co.). *EPRI Project Manager: G. W. DeYoung*

Loss of Off-Site Power at Nuclear Power Plants: Data and Analysis
NP-2301 Interim Report (RP1233-1); $9.00

This report presents a study undertaken as part of an EPRI effort to collect and analyze nuclear power plant risk data. In this study data on the frequency and duration of total loss of off-site power were collected from plants. The data were analyzed to suggest factors that influence these variables. Statistics were derived that estimate the frequency of, and recovery time for, losses of off-site power. The contractor is Science Applications, Inc. *EPRI Project Manager: D. H. Worledge*

AC Technique to Monitor Localized Corrosion in PWR Steam Generators

NP-2310 Final Report (RP1069-1); $10.50

An ac electrochemical probe for indicating the onset of rapid localized corrosion in high-temperature solutions was developed. This report summarizes the experimental methods, instrumentation, and the results of extended high-temperature testing. Impedance as a function of dc polarization is discussed, as well as the effect of heat flux on Alloy 600 corrosion. The continuous electrical probe method was demonstrated to work in alternately wet and dry crevices experiencing boiling heat transfer and to sense the buildup of impurities before actual corrosion. *EPRI Project Manager: T. O. Passell*

Interfacial Friction in Cocurrent Upward Annular Flow

NP-2326 Final Report (RP443-2); $13.50

Cocurrent upward annular flow was investigated, with an emphasis on correlating and predicting pressure drop. Attention was given to the characteristics of liquid flow in the film and to core-film interaction. Alternative approaches for correlating suitably defined interfacial friction factors were investigated. Dimensional analysis was used to define characteristic flow parameters, and an effort was made to determine how these parameters affect the interfacial friction factor. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

BWR Control Rod Cobalt Alloy Replacement

NP-2329 Final Report (RP1331-1); $33.00
NP-2329-SY Summary Report; $7.50

These reports present the results of a project to identify alternative noncobalt alloys for use as BWR control blade pins and rollers. Such alloys were evaluated and qualified for an in-reactor surveillance test. Prime candidates were subjected to a test (in a prototype facility) simulating five years of reactor service. The contractor is General Electric Co. *EPRI Project Manager: M. D. Naughton*

Steam Generator Corrosion Studies

NP-2331 Final Report (RP311-4); $7.50

A device to simulate the growth of magnetite in crevices of PWR steam generators was built, and tests were performed to study the effects of dissolved oxygen and sodium chloride on the growth rate. It was found that the growth rate could be slowed to a very low value by keeping either chloride or dissolved oxygen at near zero values. All tests were performed at atmospheric pressure and thus at temperatures below 100°C. The contractor is Centre Belge d'Etude de la Corrosion. *EPRI Project Manager: T. O. Passell*

Operation of EPRI Nondestructive Evaluation Center: Annual Report, 1981

NP-2332 Interim Report (RP1570-2); $10.50

This report describes activities at the EPRI NDE Center through 1981. These activities involve three main elements: the transfer of technology from EPRI-sponsored research projects to field use by qualification and refinement of equipment and techniques; the training of personnel, using realistic samples and mock-ups under simulated field conditions; and the encouragement of greater involvement by the academic community in providing educational opportunities for NDE careers at all levels. The contractor is J. A. Jones Applied Research Co. *EPRI Project Manager: G. J. Dau*

BWR Radiation Assessment and Control

NP-2333 Interim Report (RP819); $13.50

Work in the BWR radiation assessment and control project from 1978 to 1980 is reviewed. The major activities during this period were assessment of BWR radiation-level trends, evaluation of the effects of forward-pumped heater drains on BWR water quality, installation and operation of a corrosion-product deposition loop in an operating BWR, and analysis of fuel deposit samples from two BWRs. The contractor is General Electric Co. *EPRI Project Manager: M. D. Naughton*

Feasibility of Applications of Microwave Technology for Radioactive Wastes

NP-2334 Final Report (TPS80-756); $10.50

This report describes an investigation of the feasibility of using microwave energy for drying radioactive wastes from nuclear power plants. The fundamentals of microwave heating are discussed, and process techniques now in use and proposed techniques are reviewed. Scoping tests and laboratory tests in batch and continuous feed modes are described. A preliminary system design is also presented. The contractor is Chem-Nuclear Systems, Inc. *EPRI Project Manager: M. D. Naughton*

Application of Ultrafiltration to Radwaste

NP-2335 Final Report (RP1330); $15.00

This project assessed the operational impact of an ultrafiltration system on the processing of PWR radioactive wastes. A unit capable of supporting the radwaste evaporator operation was installed at the Ginna nuclear station, and its performance was characterized during an 18-month testing program. The unit's influence on evaporator performance, waste generation, radiation fields, and personnel exposure was studied, and an economic evaluation of the installation was prepared. The contractor is NWT Corp. *EPRI Project Manager: M. D. Naughton*

Automatic Ultrasonic Imaging System With ANL Signal-Processing Techniques

NP-2336 Topical Report (RP606, RP1125); $13.50

A conventional pulse-echo imaging system was modified to operate with a linear ultrasonic array and associated digital electronics to collect data from a series of defects fabricated in aircraft-quality steel blocks. Results showed that a combination of linear transducer array technology, advanced signal-processing concepts, and the Adaptive Learning Network (ANL) pattern recognition methodology provides significant improvements in flaw detection and characterization over conventional approaches. The contractor is Adaptronics, Inc. *EPRI Project Manager: G. J. Dau*

Hydrocyclones for Radwaste Processing

NP-2338 Final Report (RP1557-2); $9.00

Two types of hydrocyclone separators were evaluated for their efficiency in removing suspended solids from actual radwaste streams. Bypass streams were processed, and suspended solids concentration, slurry density, and particle size distribution were determined for the inlet, overhead, and underdrain streams. One separator showed typical suspended solids removal efficiencies of 82–89 wt%, which indicates that it could be beneficial in a number of radwaste-processing applications. The contractor is Radiological and Chemical Technology, Inc. *EPRI Project Manager: M. D. Naughton*

Application of an Eddy-Current Technique to Steam Generator U-Bend Characterization

NP-2339 Final Report (RPS202-2); $13.50

The application of eddy-current techniques for the inspection of steam generator tubing in the U-bend area is summarized. Two different types of U-bend transitions are described, and laboratory tests and analyses to confirm the field results are documented. The report discusses the advantages and limitations of the developed method and presents recommendations for further work. The contractor is Cramer & Lindell Engineers, Inc. *EPRI Project Manager: G. W. DeYoung*

R&D STAFF

Prevention of Condenser Failures: State of the Art

RD-2282-SR Special Report; $30.00

This report contains extended abstracts of the lectures and hard copies of the slide presentations given at the second EPRI-sponsored seminar on the prevention of condenser failures, which was held in November 1981 in Arlington, Virginia. A general overview of condenser failures, discussions of each failure mechanism, and recommendations for avoiding, minimizing, and detecting failure problems are presented. *EPRI Project Manager: B. C. Syrett*

Effect of Microstructure on Pitting and Corrosion Fatigue of 17-4 PH Steel in Chloride Environments

RD-2284-SR Special Report; $7.50

Tests were conducted in simulated steam turbine environments to determine how microstructural variations in the surface layers of 17-4 PH stainless steel (which is sometimes used for low-pressure turbine blades) affects the material's resistance to pitting and corrosion fatigue. Results are presented from two electrochemical tests performed to assess the significance of tempering temperature and shot peening on susceptibility to pit initiation and propagation. The effect of raising the tempering temperature to increase the steel's resistance to corrosion fatigue is also discussed. *EPRI Project Managers: B. C. Syrett and Ramaswamy Viswanathan*

Toughness of Cr-Mo-V Steels for Steam Turbine Rotors

RD-2357-SR Special Report; $7.50

A broad overview of the materials and design aspects of the toughness of Cr-Mo-V turbine rotors is presented. The results of recent research programs to improve toughness are emphasized. *EPRI Project Managers: Ramaswamy Viswanathan and R. I. Jaffee*

Patents

Each issue of the *Journal* includes a list of newly filed patent applications. The EPRI identification number, title, and abstract filed with the application are reprinted below. Information on obtaining a license under EPRI patent or patent application can be obtained from the Manager, Patents and Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

Information on other licensable inventions, as well as computer codes available from EPRI, is published quarterly in the *EPRI Guide*. This publication can be obtained from Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081.

Electrical coil especially suitable for high-temperature dry transformers and method of forming said coil
KD1143-01-02

An electrical coil especially suitable as the primary or secondary winding in a high-temperature dry transformer is disclosed herein, along with a particular method of forming the coil. This method utilizes an inorganic electrical insulation in the form of a fusible powder, which is coated on an unwound electrical conductor capable of being wound into a coil. After coating the conductor, the latter is heated sufficient to fuse the powdered coating such that the coating forms a continuous, substantially uniform insulating film. Thereafter, the conductor is wound into a coil having a plurality of turns, and the insulating film is caused to bond the turns together while electrically insulating the latter from one another.

Electrical coil and method of forming the same for use in high-temperature transformers
KD1143-01-03

An electrical coil especially suitable as the primary or secondary winding in a high-temperature dry transformer is disclosed herein, along with a particular method of forming the coil. This method utilizes a layer of heat-fusible inorganic insulation, preferably one that is initially in the form of an unwound strip or ribbon of separating material. This material is placed against and in layered relationship with an unwound conductor, which is also provided in the form of a strip. Both are wound together into a plurality of turns so that the separating material electrically insulates the turns from one another, and the wound coil is heated sufficient to fuse the separating material such that the latter bonds the turns together.

Low-temperature preparation of graphitized carbons, using boron and silicon
KD1200-02-01

A method for fabricating graphitized carbonaceous components for a fuel cell is provided, wherein graphitized carbon contains at least one element from the group consisting of boron and silicon. The components containing graphitized carbon exhibit improved corrosion resistance at fuel cell operating temperatures.

Clog-resistant nozzle
KD1290-01-33

A nozzle is provided for depositing molten metal onto a moving chill substrate to form a continuous metal strip. A feed chamber in the nozzle feeds molten metal through metering orifices in the nozzle to substantially fill a transfer chamber formed between two casting lips. A relatively wide mouth is formed between the lips and is located in close proximity to the chill surface of the substrate to facilitate deposition of the molten metal for casting. Molten metal in the transfer chamber isolates the metering orifices from exposure to ambient atmosphere, whereby oxidation of metal at the apertures and resultant clogging thereof are avoided.

Nonlinear resistor stack and its method of assembly
KD1421-01-05

Nonlinear resistors especially suitable for assembling into a stack are disclosed herein, along with the stack and its method of assembly. Each resistor has opposite end surfaces to which a certain electrically conductive bonding substance, specifically solder, will adhere and an outer circumferential side surface extending between the end surfaces. The entire side surface of each wafer is covered with a coating layer formed from a dielectric composition to which the specific bonding substance will not adhere. This composition is also one that is able to withstand coming into contact with the bonding substance when the latter is in a liquid state—that is, it is able to withstand the temperature of molten solder when solder is used as the bonding substance—and it must also be able to withstand the expected voltage and current levels across the wafer without any adverse effects. These coated wafers are bonded together in an end-to-end relationship with one another so as to form a stack by using the solder or other such specific bonding substance.

Radiant heat shield for a superconducting generator rotor
KD1473-01-12

A radiant heat shield for use in superconducting generators is described, which is formed by explosively welding an outer tube around an inner tube that has a plurality of coolant channels formed in its outer cylindrical surface. These channels are filled with a removable substance prior to explosively welding the two tubes together; the substance is removed after welding.

Radiant heat shield for a superconducting generator
KD1473-01-13

A radiant heat shield for use in a superconducting generator is described, which is formed by brazing an inner and an outer tube together. The inner tube has a plurality of coolant channels machined in its outer cylindrical surface. The brazing operation consists of applying a brazing compound to the outer cylindrical surface of the inner tube prior to cold working the two tubes together, followed by a heating to a temperature in excess of the melting point of the brazing compound.

Warm damper for a superconducting rotor
KD1473-01-14

A means for constructing a warm damper for a superconducting rotor is described, which uses a laminar assembly of a conductive tube and a plurality of support tubes. The conductive tube is soldered to axially adjacent support tubes and the resulting composite tube is explosively welded to two or more support tubes disposed adjacent to its radially inner and outer surfaces.

Insulated conductor
KD1499-02-13

Disclosed is a method of making an insulated conductor by coating a conductor with a triazole and applying the insulation over the triazole coating. The triazole is preferably benzyltriazole or tolyltriazole. It can be applied by dissolving the triazole in water, immersing the conductor in the solution, and evaporating the water. The invention is particularly useful with epoxy powder coatings on copper conductors that are used in perchloroethylene containing insulating fluid.

Improved catalytic combustion system for a stationary combustion turbine having a transition-duct-mounted catalytic element
KD1657-01-01

A catalytic combustion system includes a combustor having a diffuser end portion supported for sliding thermal growth by a catalytic unit through a spring clip ring assembly. The catalytic unit includes two shell portions that are secured together to support a catalytic element within the shell. A ring supports the catalytic unit on the transition duct for sliding thermal axial growth through a spring ring and receives catalytic element thrust. The parts are structurally arranged for installation and maintenance through an opening in the turbine casing.

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