# Oil Alternatives

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EPRI JOURNAL Staff and Contributors
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Graphics Consultant: Frank A. Rodriquez

Ray Schuster, Director
Communications Division



Address correspondence to:
Editor
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

Cover: Coal-oil mixtures and coal-water slurries are two possible oil replacements for utility industry boilers.

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# Fuels for Near-Term Utility Use

Phasing out oil as a utility boiler fuel has focused industry efforts on a search for alternatives. One plentiful fuel is coal, and construction of new coal-fired plants is under way. These new facilities will ease the transition in the long term, but in the near term, fuels are needed to replace oil in existing plants. On the East Coast alone the capacity of plants with boilers designed to burn oil is over 35 GW (e). Conversion of these plants to pulverized-coal firing involves extensive and costly modifications and may be impractical at those sites whose systems are geared to the use of a liquid fuel. Although some oil-fired plants that once burned coal have been reconverted, in many cases reconversion is impractical because coal storage and ash disposal areas are no longer available. So the search for a replacement has focused on pumpable slurries of coal in either oil or water.

Although each potential alternative fuel presents an opportunity to reduce oil use, it also introduces its own unique problems. These problems result from the characteristics of the individual fuel and its effect on plant output; typically, they are highly site-specific. It is therefore necessary to identify and quantify the factors involved in the use of alternative fuels so a utility can better weigh the value of each fuel against its own special circumstances.

To achieve this goal, EPRI is evaluating coal-oil mixtures, focusing on their cost and the effect they have on boilers designed to burn oil. The boilers selected for this study are large units on the East Coast, ranging from 350 to 850 MW (e) capacity with at least 20 years of remaining service life. Five of the units were designed to fire oil exclusively, and one was designed for triple-firing (oil, natural gas, or coal). The cost of modifying the plants to use a coal-oil mixture and the cost of preparing the mixture at a centrally located site are being computed. But a coal-oil mixture still contains at least 50% oil.

In an even more challenging opportunity EPRI is evaluating concentrated coal-water slurries as a direct-fired fuel. These slurries typically contain 70% finely ground coal in 30% water and will be fed directly into utility boilers. So far, only small quantities have been prepared. The slurries appear to be storable and transportable by modified oil-handling systems. By combining this technology with intensive coal cleaning, it may be possible to develop an oil-replacement option whose limitations may be tolerable even in boilers designed only for oil. Although not a perfect solution, it offers the advantages of low cost and the complete elimination of oil. The heat lost to water evaporation and the effects of slagging and corrosion, as well as added environmental control requirements, must all be quantified before the market potential of this fuel can be assessed.

A number of projects are being initiated to lay the groundwork for a utility demonstration of coal-water slurries. If the results obtained in these projects continue to be encouraging and if an adequate slurry production capability is developed by fuel suppliers, full-scale demonstration is planned to start in 1982.

In addition to the development of coal slurries, EPRI is assessing a few previously neglected fuels of lower energy value (e.g., peat and waste wood) as fuels for new dedicated facilities. Municipal solid waste is another potential energy source whose combustion would also alleviate waste-disposal problems. EPRI is sponsoring studies of these unconventional fuels at favorable sites to provide interested users with design and operating guidelines.

The invaluable experience gained in utility demonstrations will be carefully documented. But utilities often need answers long before the final reports are published, and the value of the research cannot be measured by a successful demonstration alone. To provide the timely transfer of information, a number of informal reviews for users groups and more formal "utility only" seminars have been held, and more are planned.

The work on alternative fuels is accelerating as the need for near-term options increases, as the results of the work become available, and as new viable options come to the fore. It is an exciting area of technology, and near-term solutions appear to be within reach.

Rolf K. Manfred

Rolf K. Manfred
Project Manager, Alternative Fuels
Coal Combustion Systems Division

# Authors and Articles

Many oil-fired plants are far from economic retirement, and coal-derived liquid fuels are still 10 years from full development. Conservation alone cannot bridge the gap because it is sensitive to the economy, to weather, and ultimately, to population growth. What other possibilities are there?

**New Fuels for Old** (page 6) examines two hybrids that result when pulverized coal is mixed with oil or water. Nadine Lihach, *Journal* feature writer, wrote the article, aided by Rolf Manfred, whose EPRI research projects are clearing the path for a number of near-term fuel shifts that have potential for utilities in different regions.

Manfred joined the Coal Combustion Systems Division in November 1979 after several years with Acurex Corp., where he managed projects for the design and construction of fluidized-bed combustors, coal gasifiers, pollution control systems, and coal-oil-burning and waste-burning equipment. Earlier with Aerojet Solid Propulsion Co., he was successively a chemist, group leader, program manager, and advanced technology director for the development of fuels, component hardware, and systems. Manfred holds BS and MS degrees from the University of Toledo.

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Shipping and handling costs for waste material include its burial. When the the burial costs go up five times in five years, it's time to look at ways to reduce the volume of that waste. **Advances in Low-Level Radwaste Treatment** (page 13) does just that.

Science writer John Douglas, with guidance from EPRI's Michael Naughton, concentrates on the technologies and costs for refining and compacting waste at the power plant, so the volume that remains to be shipped, handled, and buried is reduced to the minimum.

Naughton has specialized in power plant radiation control for much of his career, notably as a Nuclear Power Division project manager since August 1978 and during 13 years with electric utilities. From 1973 to 1978 he was with Boston Edison Co., becoming chief technical engineer at the Pilgrim power plant. From 1965 to 1973 he was chief chemical engineer with Iowa-Illinois Gas and Electric Co., much of the time on loan to Commonwealth Edison Co. for chemistry and radiation control at the Quad Cities plant before and after its startup. A 1957 chemistry graduate of St. Thomas College in Minnesota, Naughton also spent several years in water treatment equipment sales and consulting to the power industry.

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Environmental questions are raised by the prospect of expanded coal mining to feed a synfuels industry. Other questions pertain to synfuel combustion emissions. But most concern the chemical processes involved in converting coal to other fuel forms.

There are few pat answers to these questions. Mostly, they must be answered in a context that recognizes patterns of energy use and pollution control strategies. **Synthetic Fuels: Meeting the Costs of Environmental Protection** (page 18) was adapted by Jenny Hopkinson, *Journal* feature writer, from a conference presentation by René Malès, director of EPRI's Energy Analysis and Environment Division.

Malès came to EPRI management in February 1976 on loan from Commonwealth Edison Co. and later joined the EPRI staff. He had been with the Chicago utility since 1956, becoming director of economic research in 1965, assistant to the vice president of division operations in 1970, and manager of general service in 1973. Malès is a Ripon College graduate, earned an MBA at Northwestern University, and has served on advisory committees of Oak Ridge and Brookhaven national laboratories, the MIT World Coal Study, the U.S. Department of Commerce, and the National Academy of Engineering.

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Both a coal gasifier and a combined-cycle power plant involve flows of water, steam, and electricity, plus the pumps, valves, compressors, and switchgear to channel them. Integrating some components and functions would obviously cut redundant costs. But would all processes be forced into lockstep, preventing the power plant from following load?

**Coupling a Gasifier to a Combined-Cycle Plant** (page 22) summarizes the largely computer-based research to answer that question. EPRI's George Quentin reported on the work to an engineering conference early this year, and the *Journal*'s Ralph Whitaker edited his paper for its appearance here.

An EPRI project manager for system control research in the Advanced Fossil Power Systems Department since 1977, Quentin continues work with computer-simulated process dynamics that first engaged him at Monsanto Co. from 1965 to 1969. He later designed and taught related courses in chemical engineering at the University of New Mexico (1969–1973) and at the University of Texas at Odessa (1973–1977), where he was an associate professor. Quentin earned a bachelor's degree in chemical engineer-

Quentin

Malès

Schurr

Naughton

Manfred

ing at Rensselaer Polytechnic Institute in 1955; he was awarded MS and PhD degrees in the same field at Iowa State University in 1962 and 1965.

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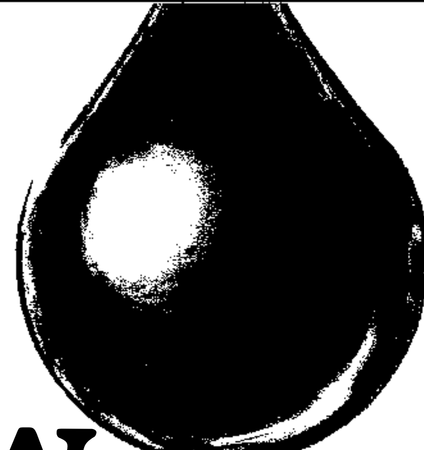
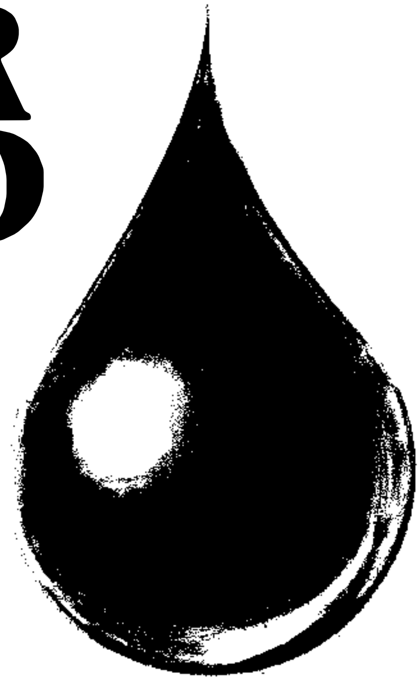
**Energy Choices: Scarcity or Abundance** (page 28) suggests that the security of our energy future requires decisions today. This article, by science writer John Douglas, reports some of the reasoning of EPRI's Energy Study Center staff.

Economist Sam Schurr, deputy director of the center, is a long-time student of energy resources and their availability. He has held his present position since March 1979 and was the founding director of EPRI's Energy Analysis and Environment Division in 1973. Between 1976 and 1979 and for 19 years before EPRI began, Schurr was with Resources for the Future, Inc., first as director of the energy and mineral resources program and later as codirector of the RFF center for energy policy research. His professional career began in the late 1930s and includes work for federal agencies, corporations, economic research firms, and the University of Chicago.



# NEW FUELS FOR OLD



Word is not final yet, but the writing is on the wall: price, availability, and policy are driving oil from the electric utility energy scene. Since 1973 the price of the residual fuel oil used to fire utility industry boilers has shot from $5 a barrel to more than $25, while oil availability has fluctuated. Federal policy now forbids the use of oil at new baseload power plants, and last year Congress considered mandating the conversion of many existing oil units to coal. In this climate of uncertainty, utilities must consider their fuel alternatives.

Some alternatives to oil are relatively uncomplicated. The construction of new pulverized-coal power plants presents no conversion problems. Some oil-fired plants that once burned coal can be switched back to coal with relatively little trouble; several units have already been so converted, and more such conversions are planned. A small percentage of oil-design boilers eventually may be modified to burn pulverized coal.

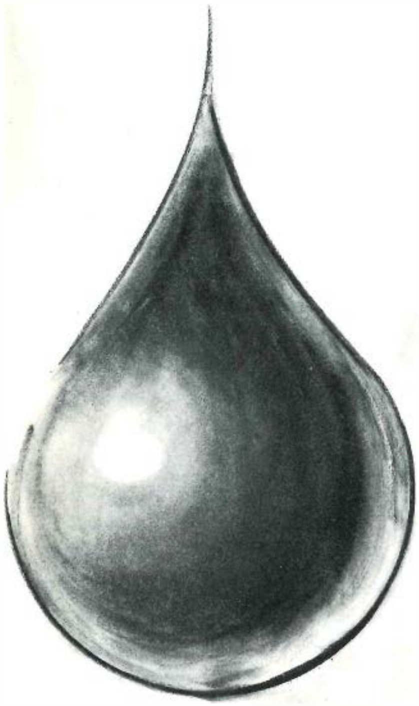
### Coal conversion problems

But for most existing oil-fired plants, conversion to conventional pulverized-coal firing is not a quick and easy choice. Many of these plants—those that were originally fired by coal but later burned oil—may not be able to meet today's pollution standards with their old ash-collection systems; they may also have disposed of their coal preparation and handling equipment, as well as their coal storage and ash disposal areas. All this can make the shift back to coal economically impractical.

Other plants—originally built as oil-fired units—require massive design modifications to cope with the ash and slag of coal firing. They lack proper fuel handling and emission control systems, and they may also lack the room for coal storage and ash disposal. For these power plants, alternative fuels may have to be found.

The search won't be easy. Synthetic fuels that could replace today's oil are still years away. Coal-oil mixtures and coal-water slurries are nearer-term possibilities that are now being actively developed. These coal hybrids offer a variety of attractions, notably the flexibility of oil without oil's expense. Coal-oil mixtures contain reduced percentages of fuel oil; coal-water slurries contain no oil at all. If these liquid fuels can be pumped, stored, and fired like oil, as tests to date indicate, the number and complexity of the alterations required to convert oil-design plants to the new fuels may be substantially reduced.

Still, there are real problems with the



Where oil is no longer an option for utility industry boilers, hybrid fuels, such as coal-oil mixtures and coal-water slurries, may be suitable alternatives. Coal-oil mixtures are typically 50% coal and 50% oil; coal-water slurries are generally 70% coal, 30% water. Through research, these alternative fuels can be on hand when needed.

new fuels. Although much has been learned about the preparation, combustion, emissions, and economics of coal-oil mixtures, these mixtures and the developing coal-water slurries are unfamiliar fuels to most utilities. So while they seem to be logical fuels to replace oil, most utilities seem hesitant to try them. Squeezed by financial hard times, utilities are short of the capital necessary to convert from oil-fired systems to untraditional alternatives, and the decision to make the investment, particularly in older plants, is a weighty one. Many utilities have therefore deferred the costly and difficult conversion decision until circumstances are clarified.

When circumstance dictates conversion—through exorbitant oil price increases, supply disruptions, or federal directives—the utility industry may have little time to respond. "All the alternatives require fairly large investments, not only in dollars, but also in time and equipment," asserts Shelton Ehrlich, manager of EPRI's Fluidized Combustion and Alternative Fuels Program. "Industrywide conversion can't happen in a few weeks or months in response to a national emergency." Yet if research such as that under way at EPRI can make these alternatives better understood, they may be adopted today by at least some utilities, explains Ehrlich. Then, should economics or policy suddenly require the conversion of large numbers of plants to alternative fuels, the technology will have been established, the designers and manufacturers will be ready for orders, and a broad base of utility experience will be available to smooth the transition. Rolf Manfred, EPRI manager for alternative fuels projects, sums up: "Our job here is to provide the necessary information to the interested utility so that it has the tools to decide what it wants to do."

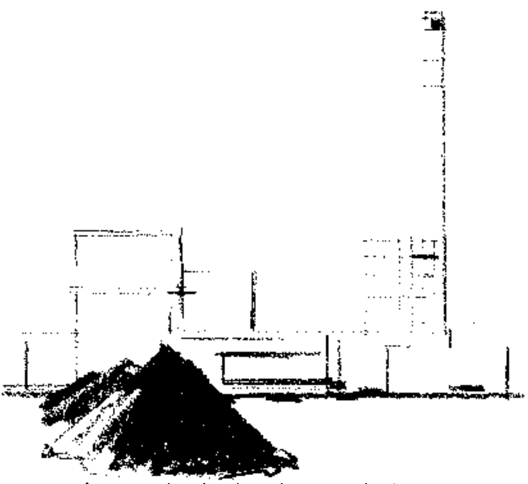
### Coal and oil

Coal-oil mixtures are the most near-term of alternative fuels. In fact, a few utilities already have demonstrations under way. These mixtures typically consist of about 50% finely pulverized coal and 50% fuel oil. They can be prepared at central locations and barged to utility customers just as oil is, explains Manfred. The burners in the steam-generating furnaces are fired with coal-oil mixtures in the same way as they are fired with oil. And because of the reduced oil content, a mixture seems as if it should be a cheaper fuel than oil.

Unfortunately, a coal-oil mixture has the undesirable qualities of coal. Coal is abrasive, so a mixture will severely erode plant pumps, pipes, and burner

# A Utility's Alternatives to Oil

When a utility can't burn oil for reasons of price, availability, or policy, its alternatives must be carefully considered. The situation at each power plant is different and calls for a different solution.



A new pulverized-coal power plant may be built to replace oil-fired power, but construction may take 8–10 years.

tips, resulting in high operation and maintenance costs. The coal can always be ground finer, but the finer it is ground, the more costly the mixture will be. The mixture will also be more viscous, and plant pumps will have to work harder to move the fuel.

Stability is another problem. When stored for long periods of time, the coal may settle out of suspension into a thick mire at the bottom of tanks and pipes. Special additives can keep the mixture homogenous, as can continuous-circulation storage systems. This adds potential operation and maintenance problems.

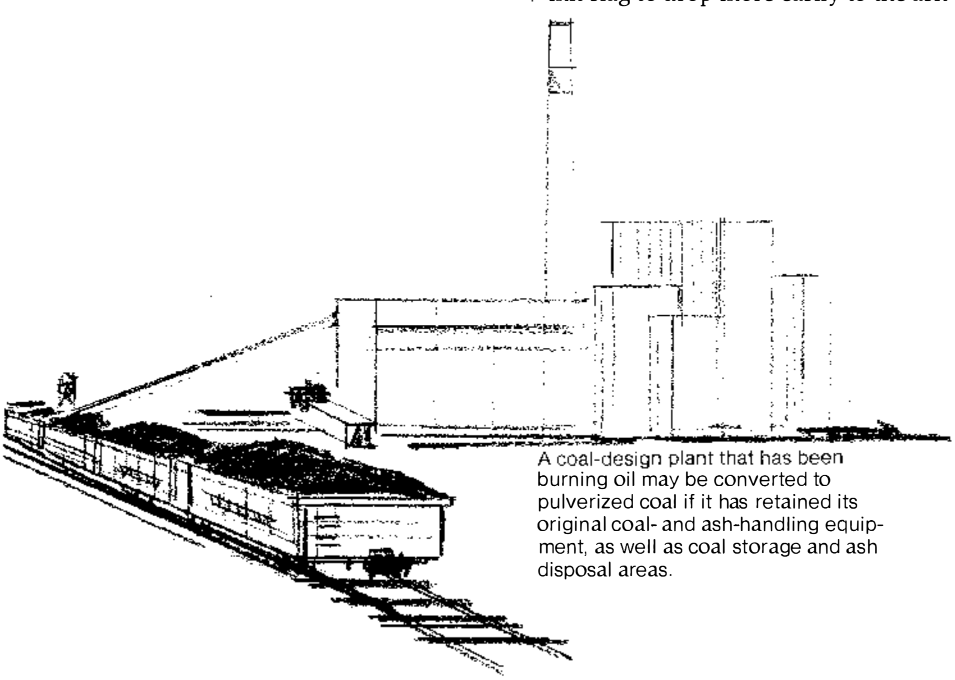
One of coal-oil's biggest drawbacks, however, is evident in the boiler. While residual fuel oil is by no means a clean fuel, coal is loaded with from 200 to 1000 times more ash than oil. When a coal-oil mixture is burned, the ash in the coal melts into a slag that fouls and corrodes the boiler tubes; the abrasive ash also erodes burner parts; bottom ash settles at the base of the boiler; and fly ash is suspended in stack gases.

The plant can be modified to accommodate this dirtier fuel. For example, soot blowers can be installed; boiler tube and burner spacing can be expanded to prevent slagging and fouling; hopper bottoms can be steeply V-shaped to permit slag to drop more easily to the ash pit below the boiler; burner design can be changed to reduce erosion. However, these modifications are very costly, and even with the modifications, the boiler will probably have to be derated to operate at 40–80% of its oil-fired capacity in order to reduce coal's adverse effects. Fly ash must also be captured by electrostatic precipitators or baghouses; the $SO_2$ produced by burning coal may also have to be collected by flue gas desulfurization systems, depending on applicable regulations. This emission control equipment is costly; it incurs a reliability penalty; and there may be no room for it at existing plants.

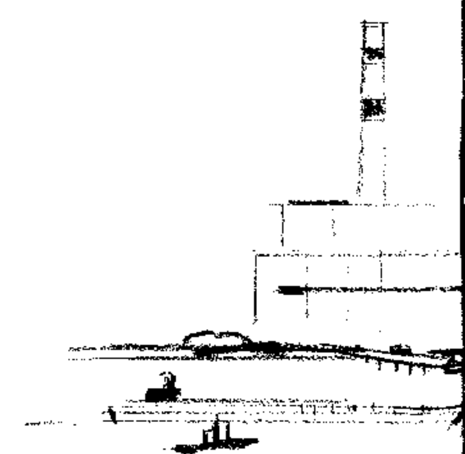
The ash and sulfur problems of coal can be reduced by cleaning the coal beforehand, but if substantial cleanup is required, the costs could be prohibitive. Low-sulfur, low-ash coal can be purchased for firing these units, but it, too, is generally expensive and not widely available. If many utilities require it to fire converted units, the supply may not meet the demand.

### Utility demonstrations

Some utilities are already trying coal-oil mixtures for themselves. New England Power Service Co. has been demonstrating a mixture at its 80-MW (e) Salem Harbor Unit 1 for over a year with sup-



A coal-design plant that has been burning oil may be converted to pulverized coal if it has retained its original coal- and ash-handling equipment, as well as coal storage and ash disposal areas.



port from DOE. At one time this unit burned coal, but it was converted to oil. The ongoing demonstration has made significant contributions in the areas of preparation, storage, and firing. Coal-oil mixtures containing up to 30% coal have been tested there, although air pollution regulations currently keep the coal content closer to 20%.

Florida Power & Light Co. has also been testing coal-oil mixtures for about a year in a 400-MW oil-design boiler at its Sanford plant near Orlando, Florida. FP&L began the tests with a 90% oil and 10% coal mixture and recently achieved a burn with 50% oil and 50% coal. At the neighboring Florida Power Corp., coal-oil will be tried at a 120-MW oil-fired unit at the Bartow plant in North St. Petersburg.

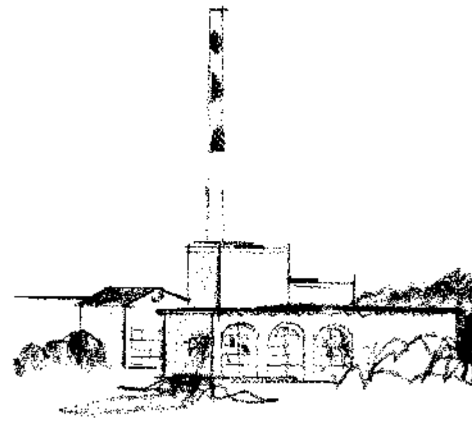
Besides these three demonstrations, approximately a dozen feasibility studies have been undertaken by electric utilities. Because coal-oil mixture cost-benefit analyses vary from plant to plant, depending on the type of coal used, boiler design, and other variables, "Utilities will have to decide how a mixture applies to their particular sites," says Manfred. So that interested utilities can more easily assess this alternative fuel, Atlantic Richfield Co., under contract to EPRI, is assembling a handbook that will be available later this year.

The handbook will be in two parts. The first part, based largely on work by Arco and its subcontractor Combustion Engineering Co., will tell users how to predict the derating that a mixture will impose on oil-design boilers. Readers can also find out how to determine retrofit requirements and costs.

The second part of the book, relying on studies by Arco and subcontractor Bechtel Corp., will advise utilities on how to predict fuel costs. "No one really knows what coal-oil mixtures will cost because the preparation plants that are currently running either are very small or use existing coal pulverizers," comments Ehrlich. So Arco developed a conceptual design of a central preparation plant on which to base its estimates. Two preparation processes are considered in the handbook, which also documents the effects of raw materials and coal cleaning on fuel cost.

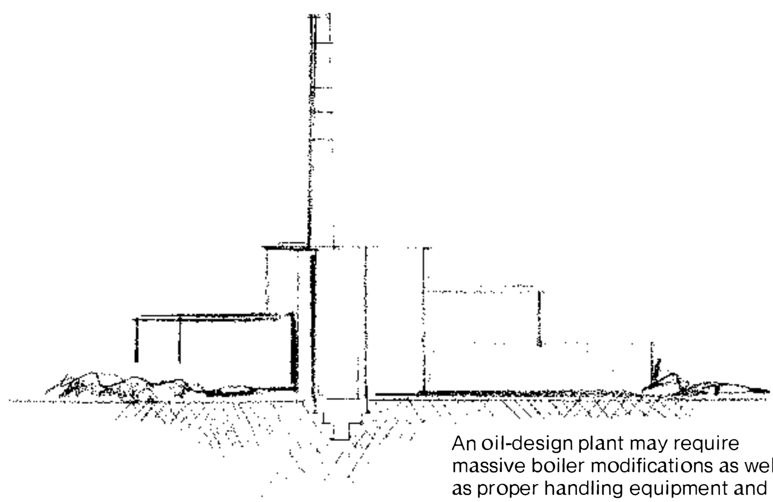
Until the handbook is available, EPRI is conducting informal users meetings to get information on this alternative fuel to utilities. Through the utility demonstrations, the users meetings, and the handbook, utilities will be able to decide for themselves whether a coal-oil mixture is the right alternative fuel for their needs.

Only a thorough assessment of a utility's existing equipment, financial position, environmental circumstances, and physical location can determine the best fuel options for a given power plant. Ongoing research will enable the individual utility to select the option most suitable for its situation.



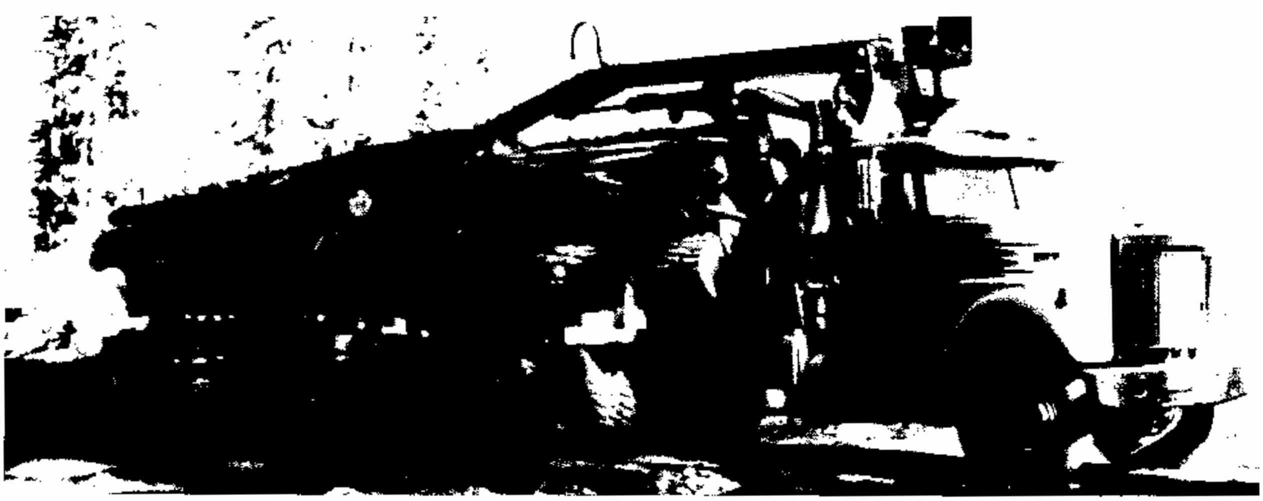
An older plant with little service life left may not be worth converting to either pulverized coal or alternative fuels.

A coal-design plant that has been burning oil might be impossible to reconvert to pulverized coal if it has disposed of its coal-handling equipment, coal storage areas, and ash disposal areas. Such liquid alternatives as coal-oil mixtures and coal-water slurries might be used instead.



An oil-design plant may require massive boiler modifications as well as proper handling equipment and storage and disposal areas in order to burn pulverized coal. Coal-oil mixtures or coal-water slurries might be more acceptable alternatives.

Beyond coal-oil mixtures and coal-water slurries, alternative fuel possibilities are municipal solid waste, peat, and wood residue. Although not strictly oil alternatives, they may be cofired with oil or coal, or used in dedicated plants in the localities where they are available. Municipal solid waste is certainly available in populated areas; peat is abundant in about seven states; and waste wood from timber harvesting litters forest floors in such areas as the Pacific Northwest. Researchers are finding out how to collect, prepare, and burn these fuels and where they will be economical.



### Coal and water

The one problem that potential users of coal-oil mixtures cannot dodge, however, is that the mixture's oil content is still relatively high. A fuel containing 50–70% oil is certainly an improvement over one containing 100% oil, but it is nevertheless subject to the price and availability problems of oil. Coal-water slurries, which contain no oil, may prove to be a near-term alternative fuel without the liabilities of oil. However, this fuel alternative contains large amounts of water, and there is some question whether it will burn outside the research laboratory. Because coal-water slurries also contain higher concentrations of coal than coal-oil mixtures, ash and sulfur problems may be exacerbated.

Despite these disadvantages, coal-water slurries are an intriguing alternative. The slurry's fuel component, coal, is domestic and relatively inexpensive. A coal-water slurry of 70–75% coal and 30–25% water might also be transported, handled, stored, and fired just as oil is. Coal-water slurry technology is advancing rapidly to the point where it might soon be a proven near-term utility alternative.

The essential requirement for utility service is the demonstration of stable coal-water slurry combustion in utility boilers. Limited combustion tests have been conducted in 1 million Btu/h, 4 million Btu/h, and 35 million Btu/h burners with encouraging results, but coal-water slurries have yet to be burned in utility boilers. Furthermore, because the combustion of these slurries will be somewhat different from the combustion of either oil or conventional pulverized coal, existing burners will not be suitable. An appropriate burner and/or atomizer design will have to be developed and demonstrated before utilities can fire this unique new fuel. And because the slurry's water content must evaporate before the coal can heat and ignite, boiler efficiency penalties in the range of 2–4% are anticipated, according to Manfred. But those penalties seem small when coal-water slurry's overall reductions in the cost of electricity are considered, as well as slurry's use of a domestic fuel supply.

Full-scale preparation systems for the new mixtures are another requirement for utility service. Preparation technology is being developed at a number of institutions, including Gulf + Western Industries, Inc., Atlantic Research Corp., Alfred University Research Foundation, Inc., and Sweden's Carbogel Ab. Various coal feedstocks, treatment systems, grinding methods, and stabilizing processes are being tried, and batches of pumpable, stable slurry as large as 25 tons have been prepared so far. Processes that can be scaled up to provide the large supplies needed by power plants are now being developed.

Perhaps the gravest concern utilities have about coal-water slurries is the derating that will be necessary when a fuel containing 70% coal is burned in boilers designed for oil. Although data on derating severity are not yet available, researchers expect that slagging and fouling will result in generation capacity losses similar to those predicted for coal-oil mixtures.

There are several ways to reduce this capacity loss. "Proper selection of coal—especially selection of a coal with a low ash content and high ash fusion temperature—is essential to minimize potential derating," says Manfred. Such coal can be secured through selective contracts or possibly through coal cleaning. As ever-higher cleaning levels become desirable, it becomes increasingly difficult and expensive to dry the fine coal, which has been wet in the cleaning process. But coal-water slurries provide a convenient solution by requiring coal that is both fine and wet.

Boiler modifications are another resort. The soot blowers, tube spacing changes, steeply sloped hopper bottoms, and other variations prescribed for coal-oil boilers are also required to deal with coal-water slurries. Should utilities wish to burn 100% oil on short notice to attain full rated capacity, these modified boilers can still burn oil if required.

Although the capacity losses threatened by the use of coal-water slurries seem considerable, the relatively low cost of the slurries is still a potent incentive to utilities whose only alternative is steadily mounting oil bills. "Fuel is a plant's highest operating expense," explains Steven Drenker, another EPRI project manager. And although coal-water slurries incur many capital, operating, and maintenance costs, costs for the basic coal fuel are not nearly as high as those of oil. In the long run, EPRI expects that coal-water slurries will be a far less expensive fuel than oil.

Auxiliary plant equipment is another area of uncertainty for coal-water slurries. This hardware, including pumps, on-line instrumentation, and pollution control facilities, will have to be carefully selected and demonstrated for use with coal-water slurry systems.

The many unanswered questions utilities have about slurries—combustion, capacity losses, auxiliary equipment—will be best settled by a demonstration in a full-scale utility boiler. Beginning this year, a new EPRI project will study some of these problems, such as slurry properties, combustion behavior, and the state of the art of auxiliary equipment. Then in 1982 EPRI plans to begin a coal-water slurry demonstration project. The Institute is now scouting for a host utility with an oil-burning unit of 100 MW or more for this test. Once the demonstration satisfactorily resolves the problems of preparation, combustion, capacity, and auxiliary equipment, utilities will have one more alternative to oil firing.

### Other alternatives

As research continues to find the alternative fuels that will make the transition away from oil easier, resources are also being funneled into some unusual fuels with a certain local appeal. These fuels, including municipal solid waste (MSW), peat, and wood residue, are not strictly oil alternatives; they may be cofired with oil or coal or used in dedicated plants. All three alternatives are drawing a considerable interest in the localities where they are available.

Garbage, or MSW, is certainly a locally available fuel possibility. The nation churns out an estimated 150 million t/yr of MSW, with an energy content of 8–10 million Btu/t, compared with coal's 24 million Btu/t. With the cost of landfill waste disposal rising, utilities are increasingly being encouraged to participate as customers in community resource recovery projects, either for unprocessed refuse to directly fire dedicated facilities or for processed refuse-derived fuel (RDF) to cofire with coal or oil in utility boilers.

A number of utilities have experimented with RDF cofiring but with mixed results, according to Charles McGowin, who manages EPRI's MSW projects. While some plants reported success, others found that RDF may not be suitable to fire in certain boilers designed for oil or coal because adverse conditions such as slagging can occur. A new EPRI project cosponsored with Argonne National Laboratory will develop guidelines for the preparation and cofiring of RDF in utility boilers. Through this and other studies, EPRI is seeking to improve the technical basis for recovering energy from MSW not only in utility oil or coal boilers but also in dedicated facilities. EPRI is also trying to maintain an up-to-date technical and economic assessment of refuse-to-energy technologies. The use of MSW as an energy alternative is highly dependent on local conditions, however.

Yet another local alternative fuel may be peat. Peat already makes significant energy contributions in a number of countries, including Ireland, Finland, and the Soviet Union. Although peat is the United States' largest potential energy resource after coal (estimated at some 120 billion [$10^9$] t concentrated in about seven states), peat has not been seriously considered as a direct-fired utility fuel until recently. Because bog peat has an 80–95% water content, it presents some unusual harvesting, handling, and preparation problems. When dry, it has a lower Btu value than lignite, the poorest grade of coal, but it is comparatively low in troublesome ash-forming minerals. The fuel is harvested in two basic ways: milling (shaving off thin layers of peat from the top of a bog and air-drying to a combustible powder) and sodding (extruding wet peat into cylinders and then air-drying).

Utilities in states with large peat resources are beginning to take stock of peat's possibilities, and an EPRI project is under way to see if this fuel is viable for utility industry power plants. From a number of candidate locations, contractor Burns and Roe, Inc., identified a site in North Carolina as most economically favorable for a peat-fired power plant. A detailed feasibility study to be completed this year will determine the cost of electricity from peat at this potential site. The cost can then be compared with the cost of electricity from coal to see if peat merits further investigation. Meanwhile, an informal users group formed by EPRI is transferring available technical information and obtaining valuable utility feedback on peat as a fuel.

Wood residue is still another local alternative fuel for possible utility use. The waste logs, snags, tops, and stumps that litter forest floors after timber harvesting are plentiful in such areas as the Pacific Northwest and currently are not used as fuel. EPRI and the Eugene Water and Electric Board (Oregon) recently completed studies that show a series of small electric generating plants fired entirely by waste wood and located within forests in the Western Cascades area of Oregon are technically feasible, but their economic success is questionable.

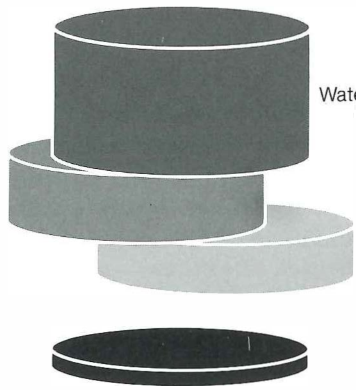
The first phase of the project identified waste wood production areas and sources, estimated resource availability and necessary processing, evaluated appropriate power plant systems, and performed preliminary environmental studies. In the second phase of the project, a site for a 24-MW power plant was selected, a system for gathering the widely dispersed forest residue was proposed, and power plant alternatives were developed. The third and most important phase of the project was an economic analysis.

The project revealed that in early 1980 there was an adequate wood residue supply in the area to run the 24-MW plant for 8 months a year for at least 20 years. Further, there were no technical problems involved with the construction and operation of such a plant. Nevertheless, the projected cost of electricity is considerably higher than the present cost of electricity in the area; the availability of wood residue, although apparently adequate right now, will most likely shrink because of increased demand by pulp manufacturers, and long-term supply guarantees from the U.S. Forest Service were also uncertain. Plainly, local conditions can make or break such alternative fuel propositions.

### Informed decisions

As research begins to provide the answers to the questions utilities have about coal-oil mixtures, coal-water slurries, and other alternative fuels, informed decisions can begin to be made about the energy future. With research results, utilities can consider their own situations carefully. Their existing equipment, financial position, environmental circumstances, and physical locations can be taken into account, these factors compared against the demonstrations and the data, and an intelligent choice rendered. Through the research described above, alternative fuels can be on hand when needed.

This article was written by Nadine Lihach. Technical background information was provided by Rolf Manfred, Coal Combustion Systems Division.




# Advances in Low-Level Radwaste Treatment

Volume reduction systems allow utilities to avoid the cost of transporting and burying the uncontaminated portions of low-level radioactive waste. After driving off the water, air, and combustibles, a binder is added to the contaminated solids.


With advanced systems, economic feasibility is now evident and utility commitments are being made.

Amounts as little as 5% of the volume of low-level radioactive wastes shipped from a typical nuclear power station for burial may actually be contaminated solids. The rest is largely water, air, or combustible organic material. Until about five years ago, disposal of such radwastes was inexpensive, so the extra volume caused little concern. However, from 1975 to 1980, burial costs per cubic foot rose roughly fivefold, and transportation costs per mile rose by nearly one-half. As a result, some long-abandoned techniques for reducing the volume of low-level radwastes are being reexamined, and new treatment processes explored.

The history of radwaste treatment on the site of a nuclear reactor—particularly the incineration of contaminated trash—is surprisingly long. A very early experimental program was carried out at the Argonne National Laboratory from 1951 to 1953. The program was successful, and most of the component designs of the Argonne incinerator system can be found in today's commercial systems. However, the program was terminated in 1953 because it became cheaper to ship the wastes to Oak Ridge National Laboratory for burial.

Today this economic picture has changed substantially. Packaging, shipping, and burying radwastes can now range up to \$18/ft$^3$ (\$640/m$^3$), depending on distance from the burial site. By comparison, the original ANL operating cost figures, updated for inflation, indicate an incineration cost of \$12/ft$^3$ (\$420/m$^3$). However, during the intervening years, a variety of other problems have arisen, indicating the need for advanced treatment systems.

The technical problems facing older incinerators can be illustrated by the experience of the Yankee Atomic Power Station at Rowe, Massachusetts. For 10 years, the station had a commercial incinerator in operation. The unit was quite simple by today's standards, requiring a lot of hands-on operation. Trash had to be manually sorted prior to incineration; this, combined with the discomfort of working near the heat produced by the unit, made the operation unpopular with the station's staff. In 1977, use of the incinerator was terminated because the need for new off-gas cleanup equipment arose, and the station management felt that capital improvements to such an old unit were not justified.

### Technical options

Whether the incineration of contaminated trash can be carried out safely and economically in nuclear power plants is still the subject of active debate among utilities, engineers, and vendors. In Europe, Canada, and Japan, such incinerators have been used for volume reduction of power plant wastes for approximately 5 years, and in nuclear research centers, for nearly 20 years. DOE is now sponsoring a large and active program for the development and testing of incinerators, which remain a part of most commercial radwaste volume reduction systems. But other technical concepts have also gained prominence.

Generally speaking, volume reduction processes can be divided into four categories, various combinations of which may be included in a large commercial system.

□ Crystallization. Much of the water can be removed from liquid wastes by evaporation at pressures near atmospheric, although some vacuum-cooled equipment is in use. The remaining product of this crystallization process is a slurry of solid crystals in a saturated solution, which is often quite viscous.

□ Dehydration. Practically all the water can be removed from some wet wastes, leaving a dry residue composed of nearly anhydrous solids. The term *dryer* is appropriate for dehydration equipment that does not involve removal of volatile oxides as well as water. (Oxide removal requires a type of dehydration called calcination.) Some air is also removed from the waste during dehydration, as porous materials collapse under heat, but this is largely a side effect.

□ Compaction. The more commonly used technique for removing air from dry active waste is baling or compacting into drums. There is also an application of compaction as part of the final solidification process, in which the residue from dryers or ash from incinerators is mixed with a binder and extruded or pelletized.

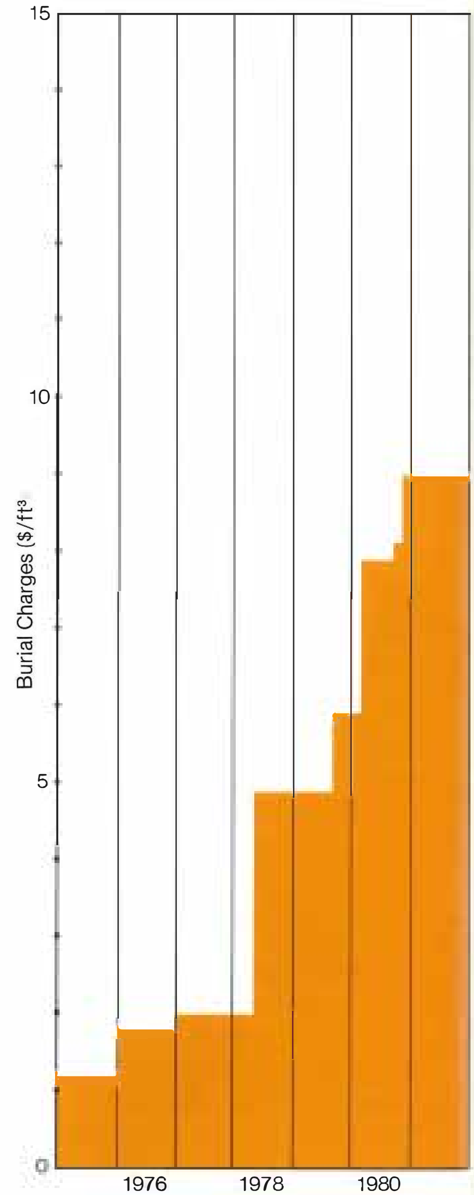
□ Incineration. The major role of incineration as a component in a large volume reduction system is to remove combustible organic material. Some water and air can also be driven off as a side effect.

An EPRI study of commercial volume reduction systems has been completed recently, and Michael Naughton, project manager in the Nuclear Power Division, says the report is designed to provide utility planners with definitive information on an important technology now commercially available in the United States. In addition to providing brief technical descriptions of specific volume reduction systems, the report lists utility commitments made for commercial installation and assesses the economic outlook for the technology.

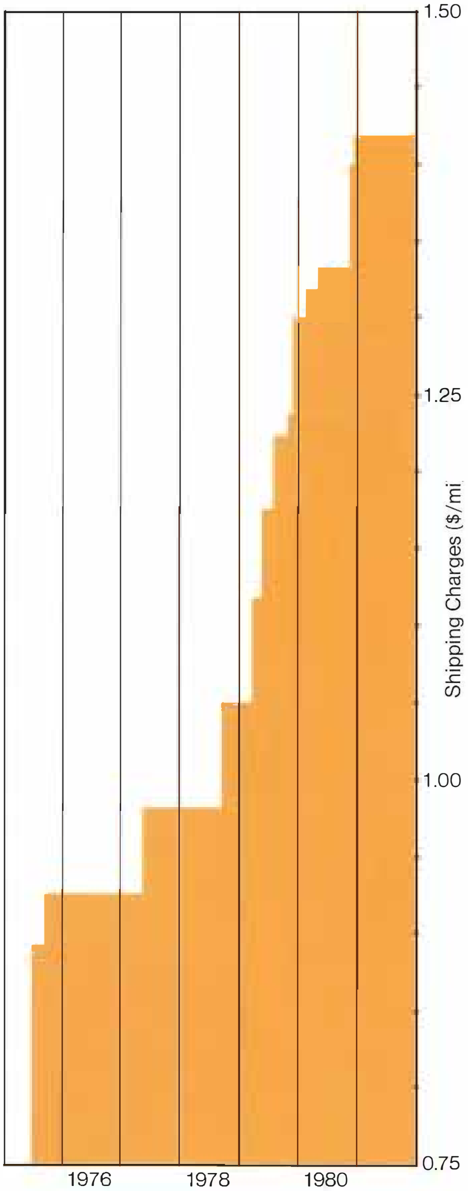
A key feature is a detailed model designed to represent the waste output of a typical nuclear power plant. Within a carefully specified set of caveats, the model can be used to estimate the economic effect of volume reduction technology on a typical plant and the investment parameters needed to justify its installation. In the model, the volume of radwaste shipped annually for burial is about 23,000 $ft^3$ (650 $m^3$). Of this total volume, 8600 $ft^3$ (240 $m^3$) is air, 4600 $ft^3$ (130 $m^3$) is water, and 3500 $ft^3$ (99 $m^3$) is combustible organic material. In addition, 5200 $ft^3$ (150 $m^3$) of inert binder material is included for solidification. This leaves approximately 1100 $ft^3$ (30 $m^3$), or 5% of the total volume, that is composed of inert, radioactively contaminated solids.

The study shows that by using a combination of techniques, advanced volume reduction systems can achieve a better reduction than traditional systems by a factor of 2 or 3. For example, in reducing the volume of salt slurries (a common form of waste, especially in boiling water reactors), normal liquid evaporators can remove about 95% of the water, resulting

Economics is the driving force behind the renewed interest in volume reduction systems for low-level radioactive waste. In



the last six years, buried costs per cubic foot have risen by nearly 700% and shipping charges per mile by over 50%.




in a product that is about 25% salt, by weight. Evaporative crystallizers cover a range up to about 50% concentration, cutting that volume by half. A dryer system can then remove virtually all the remaining water, which again results in a reduction by half of the volume of packaged waste to be shipped.

To provide a cost-benefit assessment of retrofitting a volume reduction system on an existing plant, the study considers the case of a typical station to which a dryer and an incinerator have been added and where wastes are finally solidified in cement. Assuming a 2300-mi (3700 km) shipping distance, disposal costs for untreated wastes would be $1,514,000, according to the model. Installation of volume reduction equipment could reduce this figure to $592,000. The model's conclusion is that such savings could justify an initial capital expenditure of about $9 million, assuming the equipment had a 10-year life. For a 30-year life, an investment of $25 million would be justified. Of course, no generic analysis can ever be appropriate for a specific station because many of the important parameters are site-specific.

**Utility commitments**

Within the limits of the model presented, the study does offer evidence that volume reduction technology has finally gained economic feasibility. It is no surprise, then, to find that 13 utility commitments have been made to install advanced volume reduction facilities, at a cost of about $10 million per site. Nine companies are currently offering volume reduction equipment and four others are potential suppliers. If present schedules are met, the first operating power plant to have a new volume reduction system will be the Palisades station of Consumers Power Co. Scheduled to start operation in August 1981, the facility will use the extruder-evaporator dryer and solidification system of the Werner & Pfleiderer Corp.

Specific commercial systems offer several different combinations of the basic components, as well as a variety of advanced technologies. Some examples follow.

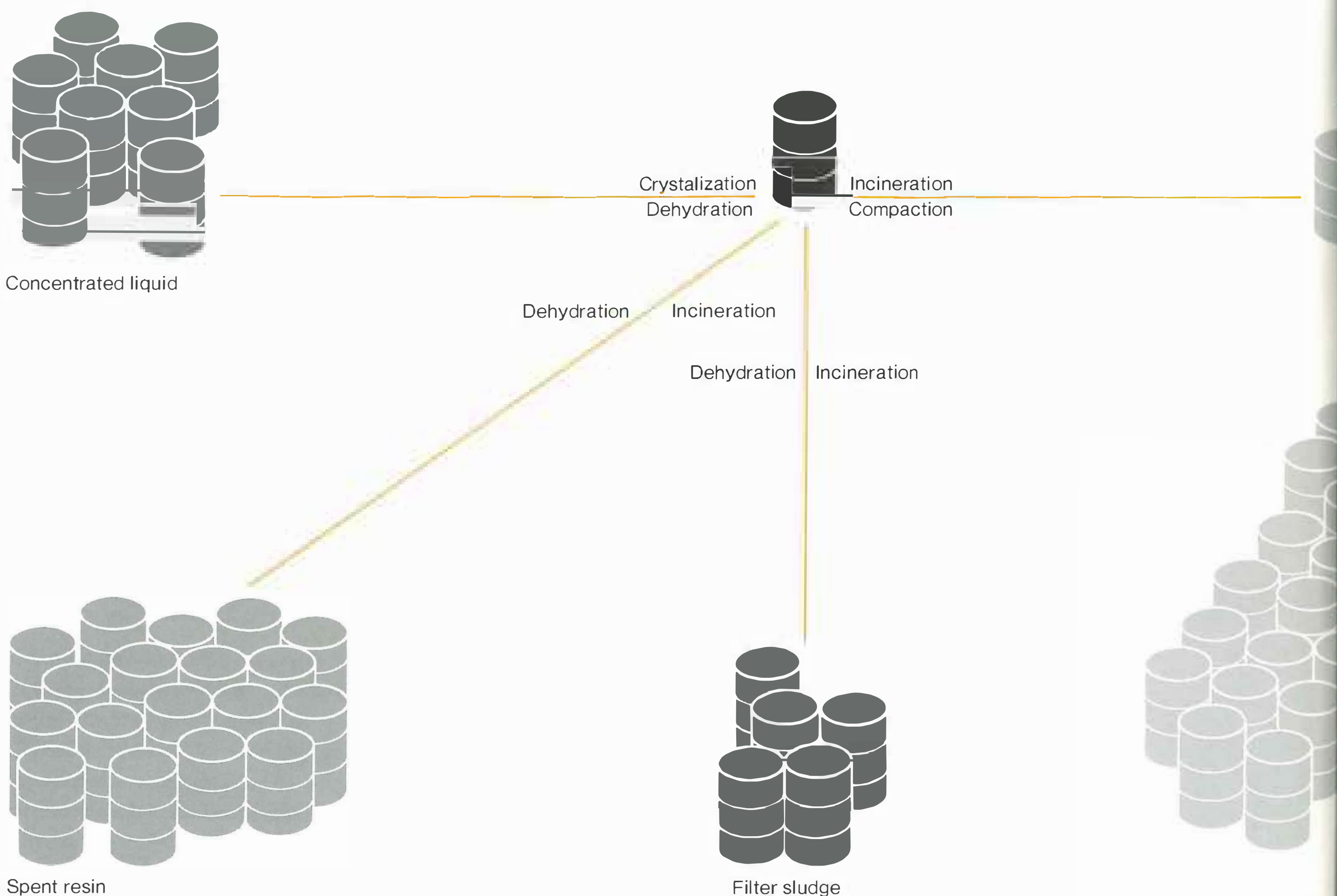
*Fluidized-Bed Systems* In a fluidized bed, particles are suspended in a stream of air, which provides for very efficient drying or burning. The Aerojet Energy Conversion Co.'s volume reduction system uses fluidized beds in both its dryer and its incinerator. In the dryer the liquid radwaste is atomized on the hot bed of particles, instantly vaporizing the water and leaving a fine residue that coats bed particles and is removed with them. The fluidized-bed incinerator can handle a variety of wastes, including dry active waste, contaminated oil, and spent resins. A full-scale prototype unit is in operation at the Aerojet facility in Sacramento, California.

Newport News Industrial Corp. uses a single-vessel, multipurpose fluidized bed that can dry liquid wastes and incinerate combustible materials, resins, and sludge. The bed is composed of an inert medium that is identical for both the incineration and the drying modes of operation. Residue is carried from the vessel with the gas stream and removed in an off-gas cleanup system. The company is participating in the operation of a pilot plant with Energy, Inc., at the latter's facilities in Idaho Falls, Idaho.

*Bitumen Systems* Molten bitumen, or asphalt, can be used to supply the heat in an evaporator/dryer, and then cooled to entrap and solidify the residual radwaste. In a system used by Associated Technologies, Inc., waste and molten bitumen are simultaneously fed into the top of a vertical thin-film evaporator, where rotating blades spread a thin coating of the mixture on the heated interior surfaces, and the water is evaporated. Solidification of the homogenous mixture emerging from the bottom occurs directly within the container used for burial. This type of system is currently used at power stations in Japan and Sweden.

Werner & Pfleiderer Corp. is offering a system in which molten bitumen is

Applicable techniques for reducing the volume of four generic types of low-level radioactive waste. Relative compression ratios for each type are shown.



mixed with radwaste by rotating screws in a horizontal extruder-evaporator. The dry waste residue particles are embedded in the asphalt and extruded into a burial container. Several Werner systems are being used in Europe, and the company operates a pilot plant system at its New Jersey facility.

*Crystallizer Systems* Evaporative crystallizers have become more widely accepted in the past five years or so. In the Westinghouse Electric Corp. version, the crystallizer chamber consists of a conical tank and an inner circular baffle that separates the forming crystals from a clear recycle stream. Heat is applied in a vacuum, and once a sufficient volume of waste crystals has formed, the operation is terminated and the crystalline slurry is pumped into a cement solidification subsystem. The system is still under development, but all components have been tested on a reduced scale. A full-scale prototype is being built in Westinghouse's Pensacola, Florida, facility.

Little information has been made publicly available about a crystallizer system being developed by Hittman Nuclear and Development Corp. A thin-film evaporator is used to form the crystals, and components have been separately tested, but no prototype system has been assembled. There are several other suppliers of radwaste crystallizers, including HPD, Inc., which has equipment installed in several power stations.

Dry low-level waste

*Blender-Dryer System* Teledyne-Readco has developed and is marketing a volume reduction system that uses a blender with a steam jacket to evaporate water; after evaporation the dry product is transferred to a hopper for solidification. A pilot plant version of this system has been operated, but no commercial facilities have been constructed.

*Glass Furnace System* In this unique system, called a Pyro-Converter by Penberthy Electromelt International, Inc., radioactive wastes, wet or dry, are placed on the surface of a pool of molten glass. Any water content is flash-evaporated and the ash is dissolved in the glass melt. Although the system has several drawbacks for power plant application (complete feed and off-gas systems have not yet been fully designed), it may prove useful for disposing of certain difficult wastes. The system has been tested at the commercial demonstration scale.

### Future activity

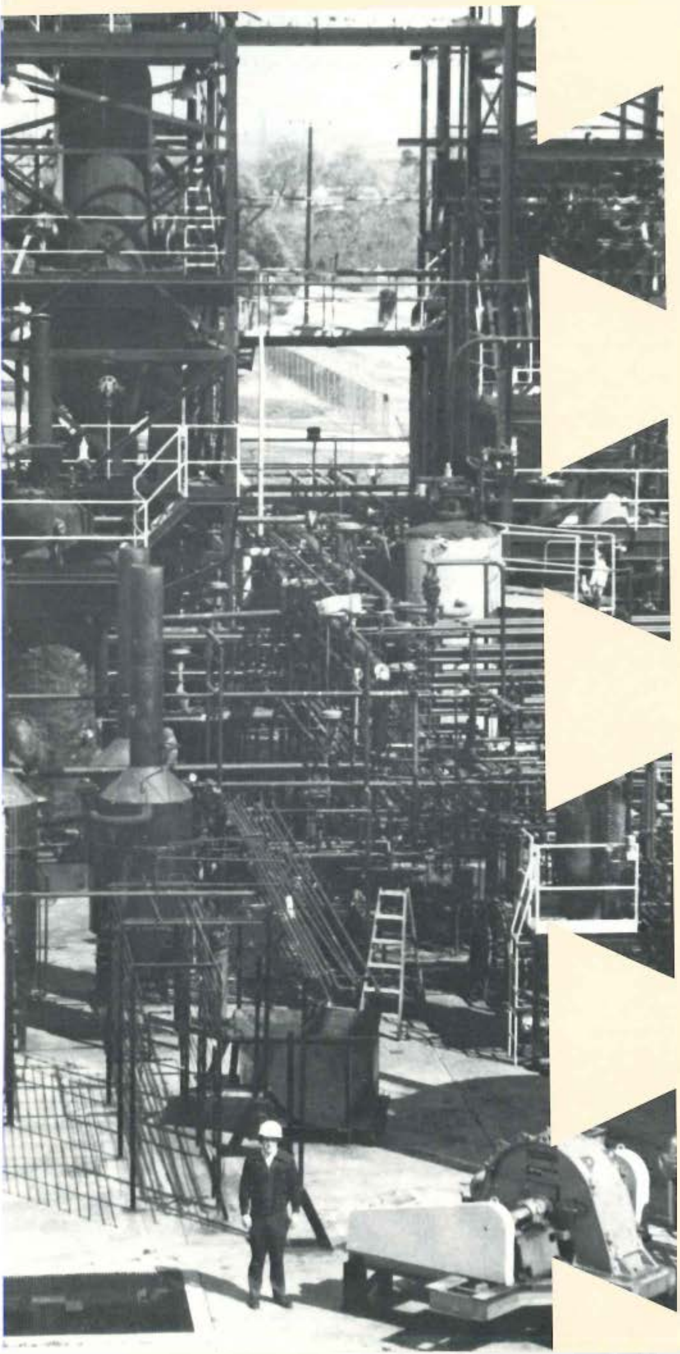
Other systems may become available in the future. United Technologies Corp. and General Electric Co. have developed and demonstrated a process that mixes a small stream of waste into a large stream of hot, inert fluid. Helix Corp. is modifying an incinerator developed at Los Alamos Scientific Laboratory that uses a primary combustion chamber with an afterburner. Combustion Engineering, Inc., is developing an incinerator in which residues from evaporators are sprayed into the combustion chamber. And UNC Nuclear Industries, Inc., is preparing an integrated drying and solidification system, the details of which are still proprietary.

The EPRI project that is monitoring these developments will continue. Performance data of systems in this country will be incorporated into future reports as new equipment is installed and placed in operation. The focus of the project, according to Naughton, will be to "provide a comparative assessment of system economics and operational characteristics. The final objective is to present information the nuclear power industry can use as a planning tool."

One conclusion of the project is already clear: As the subject of radwaste continues to demand public attention and the costs of shipping and burying the wastes continue to mount, volume reduction techniques will likely become an even more important part of the nuclear future. ■

This article was written by John Douglas, science writer. Technical background information was provided by Michael Naughton, Nuclear Power Division.

# Synthetic Fuels: Meeting the Costs of Environmental Protection



**Increased coal use, particularly in the form of synthetic fuels, will have to interlock with this country's environmental objectives. But the cost, availability, and reliability of environmental controls must also be considered.**

Over the last decade the United States has slowly been coming to the realization it has arrived at a turning point in its energy-economic system. The limits on natural gas use, the formation of OPEC, the oil embargo, the escalating price of fuels, the formation of various government energy agencies, the Iran-Iraq war are just some of the markers along this path of realization.

It is now generally accepted that oil and natural gas are being used at a rate that is not sustainable. The energy-economic issue is what to do about it. One approach advocated by many is the development of synthetic liquid and gaseous fuels from coal. To determine if this is a viable alternative, we have to know, among other things, if such a development is environmentally acceptable.

To answer the question of whether synthetic fuels can meet our environmental goals, we must have answers to a whole series of questions: What are the synthetic fuel needs? What are the appropriate environmental goals? Which effluents are of environmental concern? How do these effluents compare with those from other energy systems? What are the costs of not meeting our energy requirements?

To understand the outlook for synthetic fuels, we must have clearly in mind the energy outlook for the United States. The first step in this understanding is to look at the national energy picture and then the part played by each of the fuels.

In 1979 the United States consumed about 80 quadrillion ($10^{15}$) Btu of energy. Almost one-half of this energy was in the form of oil, and about 40% of that oil was imported. Natural gas made up about 25% of the fuel used in 1979. Both oil and natural gas are now viewed as fuels in short supply. Further, price increases for oil and gas make coal the bargain fuel of today, although coal filled just 20% of energy needs in 1979. Hydroelectric and nuclear power each furnished about 4% of the energy requirements. Renewables, such as solar, biomass, garbage, and geothermal, satisfied less than 1% of the total energy need.

There is great debate over how much energy we will need in the future. Using the year 2000 as a benchmark, most estimates range between 100 and 130 quadrillion Btu, or 25% to 60% more than we are using today. The uncertainty in the figure reflects debate on two issues: the size of the economy and the efficiency with which that economy will use energy.

With regard to the economy, there are some further considerations, such as the composition of the workforce, the length of the workweek, the productivity of the workforce. But leaving aside these details, it is relatively easy to calculate a reasonable estimate of what an economy of minimum growth should produce so each person at the turn of the century is no worse off than his peer today. That necessitates close to a 70% increase in the gross national product. A greater relative increase in the past has enabled the upward mobility of our society and probably would be desirable in the future.

The other uncertainty is the improvement in energy use. Over the last eight decades energy efficiency has improved by nearly 50%. Because of the recent jump in energy prices and our national focus on improving efficiency, we would expect a slightly better-than-average performance in the future. This will be offset by the need to employ less-convenient fuels, meet more-stringent environmental standards, and work with less-rich resources. In any case, we believe a 20% improvement in efficiency to be a reasonable expectation.

This minimum economic growth combined with a reasonable expectation of conservation leads to an estimate of energy required of nearly 110 quadrillion Btu. This means that we have to find 30 quadrillion Btu of additional fuel resources plus 12 to replace oil that we now import, plus additional fuel to replace any lesser domestic production of oil and natural gas, plus the fuel to make up for any shortfall in the nearly 30 quadrillion Btu we are counting on from conservation, and plus the fuel for any greater energy requirement than the 110 quadrillion Btu we assumed.

The potential sources are coal, solar in all its manifestations, uranium, and geothermal. Production of oil from shale, bitumens, or tertiary recovery may be one way to keep domestic oil production close to present levels. Similarly, nontraditional sources of natural gas are viewed as a possible way of keeping total gas production level.

Coal will have to assume an important role. We see its production rising from 700 million tons today to 1.8 billion ($10^9$) tons in 2000. This amounts to 40 quadrillion Btu. On top of that, we expect 200–400 million tons for coal export.

A major share of coal use will continue to be in electric utility boilers. The rapid and successful development of a synthetic oil and gas industry could be critical if this rapid increase in coal use is to be digested by the economy. It could be even more critical if nontraditional sources of oil and gas turn out to be more expensive and more difficult to extract than presently thought. In any case, a viable synthetic oil and gas industry provides the insurance that the transition from the 1970s' fuel mix to that of the twenty-first century can be made without constraints on the economy.

One essential question is whether the transformation of coal to synthetics can be done in a way that meets our environmental objectives. To answer the question, one has to understand what these objectives are.

## Environmental objectives

When the environmental movement began in the 1960s, it built its constituency on the basis that past industrial and societal practices had not fulfilled their environmental stewardship role. Damage to ecological systems was obvious: unreclaimed land, extinction of certain species, degradation of aquatic systems. In the enthusiasm to reverse prior shortcomings, the rallying objective became zero discharge.

But as progress was made in implementing such objectives in legislation, regulation, and mores, the virtual impossibility of achieving such an objective became clear. Man's very existence made inconsistent the possibility of having no effect on the environment. The achievement of this objective by the extinction of the human species was unacceptable except to the most radical in the movement. Moreover, it also became clear that Mother Nature in her natural state was not all that benign, allowing unpleasant bacteria and viruses to bring disease and inconsistencies in weather to wreak havoc. Man could and did improve on the natural plan.

But in so doing, man created effects that should be controlled. The next philosophy to be adopted, one which still holds considerable sway, is that the best of available technology should be used to control effluents. However, we are just now beginning to learn that our engineers' inventiveness may lead us to bankruptcy if we implement such a philosophy.

We are now in the process of evolution toward an objective of cost-effective application of environmental control. While this is a laudable goal, we find problems here too. The exact nature of environmental effects is difficult to foresee. And even when we can determine the effects, translating such imponderables as a clear view, a clean water course, or a human life into a metric comparable to those used to measure tons of concrete, human labor, and energy is very difficult.

In the World Coal Study, participants tabulated the standards for emission of effluents for a number of countries. Similarly, they listed standards for maximum ambient concentrations of pollutants. It surprised many to see the wide disparity of standards among nations. Yet, when one considers that each nation is trying to reflect its own perception of cost-effectiveness, these differences do not seem quite so strange.

There are four basic reasons why such regulations differ. First, values differ among societies. In areas that are very poor, additional inexpensive energy is valuable, while human life is appraised as not so valuable as in societies where there is already great luxury. Second, regional differences in meteorology, topography, population density, and resource distribution lead to different needs in achieving identical environmental objectives. Third, there exists a substantial uncertainty in the data about effects of pollutants on health and ecology. Individual nations interpret this uncertainty differently. Fourth, cultural approaches to achieving objectives will lead one region to legislate regulations, while another will achieve the same result by mutual consent.

It follows that different nations may approach the setting of environmental standards for synthetic fuel production differently. The question is whether a synthetic fuel industry can be found environmentally acceptable at a reasonable cost. The answer is actually easier to derive than might be imagined if we assume rational policies. This is because the standards should be set relative to the alternatives. To simplify this discussion, let us consider only two alternatives: burn coal in a boiler or risk not needing the energy.

If we assume that the coal will be used in any case, then the question of environmental effects from mining is a virtual trade-off. It may be that a synthetic fuel industry might need slightly more coal to obtain the same amount of useful energy because of losses in conversion. However, that is a debatable subject, depending on the alternative forms of coal use. But more important is that coal mining and transport can be practiced in a manner deemed acceptable to those nations that mine coal. Even though this involves a higher cost than a decade ago because of added mine safety, reclamation practices, subsidence control, and water effluent control, coal is being produced and delivered at a cost substantially lower than oil or incremental natural gas.

The major environmental debate on synfuels production surrounds the processing plant itself. There are four basic areas of concern: air effluents, liquid and solid wastes, water contamination, and water use.

The processing of coal into a synthetic fuel resembles oil refining or a chemical process more than the boiler use of fuel. The eventual combustion of the synthetic fuel, of course, is a process like the boiler use of coal.

In the conversion process some gaseous molecules can escape. Generally, the amounts are extremely small. However, because in some conversion processes many of the hydrocarbons pass through molecular states that are highly toxic and possibly carcinogenic, releases of these gaseous products are of concern. By engineering design, routine releases can be reduced and risk of accidental releases minimized. The costs of such process designs do not seem prohibitive, but the standards have yet to be fixed and no waiver from eventual standards seems likely for the first commercial plants.

In the combustion of synthetic fuels, the comparison must be made to the alternative of direct combustion of coal. Here, synthetic fuels have the advantage of having had removed most of the contaminants in coal, such as sulfur and trace elements. Test burns of synthetic oil in utility boilers have not indicated any substantial difference in effluents when compared with the burning of natural oil. Slightly higher levels of $NO_x$ have been observed, but these may be process-specific. In any case, such emissions could be controlled to what most believe are the prospective standards.

Again, because the synthetic process creates some molecules that are known to be hazardous, there is a concern that the liquid or solid wastes from the conversion plants could be an environmental hazard.

One level of concern is the occupational hazard to those working around the plant, in the transport of the fuel, or in its eventual use. There is an added hazard here, compared with direct coal use, although the coal dust problem is eliminated. The risk, however, seems roughly comparable to that of handling products from a petrochemical plant, and it means continuous care to limit occupational exposure.

The solid-waste streams, at least for the limited number of plants examined so far, appear no different in toxicity and general character from the fly ash and bottom ash from a utility boiler using the same coal. Methods for handling such wastes are well-developed and reasonable in cost.

A substantial amount of water is required in the synthetic fuel processes, some of which is returned through plant waste streams. Generally, waste treatment can maintain water quality at whatever level is desired. Most of the concern is associated with the entrainment of solid or liquid wastes containing such pollutants as trace metals and polycyclic organics. These can be controlled by existing industrial practice, although the degree of control will be commensurate with the acceptability of costs. Costs generally increase with more stringent controls. However, knowing the exact emissions from any one plant depends on which feedstocks and which combination of technologies are used.

Of more concern are the large amounts of water used in the process. There are a few areas in the United States where water is truly in short supply, and there are many areas where all water rights are spoken for. In areas where water resources are short or already fully allocated, there is concern for the dedication of water resources to synthetic fuel plants. This can be solved by building plants in areas with abundant water supplies, by importing water from other regions, or by using water supplies that are unusable for other purposes. All these alternatives increase the costs. This may indicate that coal resources in certain regions cannot be applied to synfuel production because of limitations on water availability.

### Environmental issues

This brief review indicates that the environmental effects of synfuel production are probably manageable at a relatively small cost. A former EPA administrator, Douglas Costle, told the Board of Directors of the U.S. Synfuels Corp. on December 22, 1980, that synfuel developers can build plants to meet current federal environmental regulations. But he added that the potential environmental hazards presented by synfuel production "are real and substantial." At the same meeting of Synfuels Corp., Costle went on to say that EPA did not plan to go ahead and "announce the rules of the game, so the [synfuel] industry can get on with its business." He called this approach to setting standards unrealistic and impractical. Instead, "it will be the terms and conditions of individual permits that determine environmental controls for the first generation of plants." Is it possible to get venture capital to step forward when faced with such uncertainty as to the cost of environmental control?

This is a dilemma between the desire for certainty in protecting the environment and the desire for certainty in protecting economic viability of billion-dollar plant investments. This dilemma leads to our current impasse in face of what appears to be an important national objective of demonstrating the commercial availability of synfuel technology.

Were the issue one dealing with the outcome of a poker game, we might be able to afford the luxury of delay as each side tries to outbluff the other. There is a growing realization that we are facing a severe energy crisis if we do not change from the pattern of the past. Specifically, we need to find ways to substitute coal for oil and natural gas and provide coal as the major source of increased fuel for our society. Synthetic fuels may well be a major requirement for that transition.

However, the entire dimension of the cost of failure may not be clear. At EPRI we have studied the cost of short-term electricity outage and find that it averages $2 to $3 per kWh, compared with the market price of 5¢ per kWh.

What are the potential costs of a long-term energy shortfall? It is difficult to predict confidently. It may result only in small inconvenience as we are unable to satiate our desires or meet our goals of economic growth. It is more likely to involve social conflict that pits poor against rich, old against young, residential against industrial, new against old customers. Even more serious, it may presage international social disruption as we, with our stronger economy, muscle out weaker industrial nations and very weak developing nations for the limited oil supply.

The epitome of disaster is international conflict over inadequate energy sources. Historians generally believe that past international conflicts have been spawned, or rationalized, on economic issues. The risk of not finding an environmental compromise acceptable to all parties—a compromise that will allow the rapid development of a synthetic fuels industry—appears as important as the risk of degradation of our environment from coal use. Surely, there must exist some middle ground on which rational men can agree.

### Further reading

World Coal Study. *Coal—Bridge to the Future.* Cambridge, Mass.: Ballinger Publishing Co., 1980.

This article was adapted by Jenny Hopkinson from a speech by René Malès at the synthetic fuels conference, San Francisco, February 20, 1981. Malès is director of EPRI's Energy Analysis and Environment Division.

A promising technology for converting the fossil energy of coal into electric power is the gasification–combined-cycle (GCC) power plant. It first converts coal to gas, from which sulfur compounds are easily removed, and then burns the clean gas in a combustion turbine at a temperature of 2000°F (1100°C) or higher. A heat-recovery steam generator uses the exhaust gases to power a steam turbine.

In some systems, waste heat from the gasifier can be used to produce additional steam, a step that couples the fuel gas process with the combined-cycle power plant. This emphasizes the essential integration of the fuel gas production and electricity generation processes.

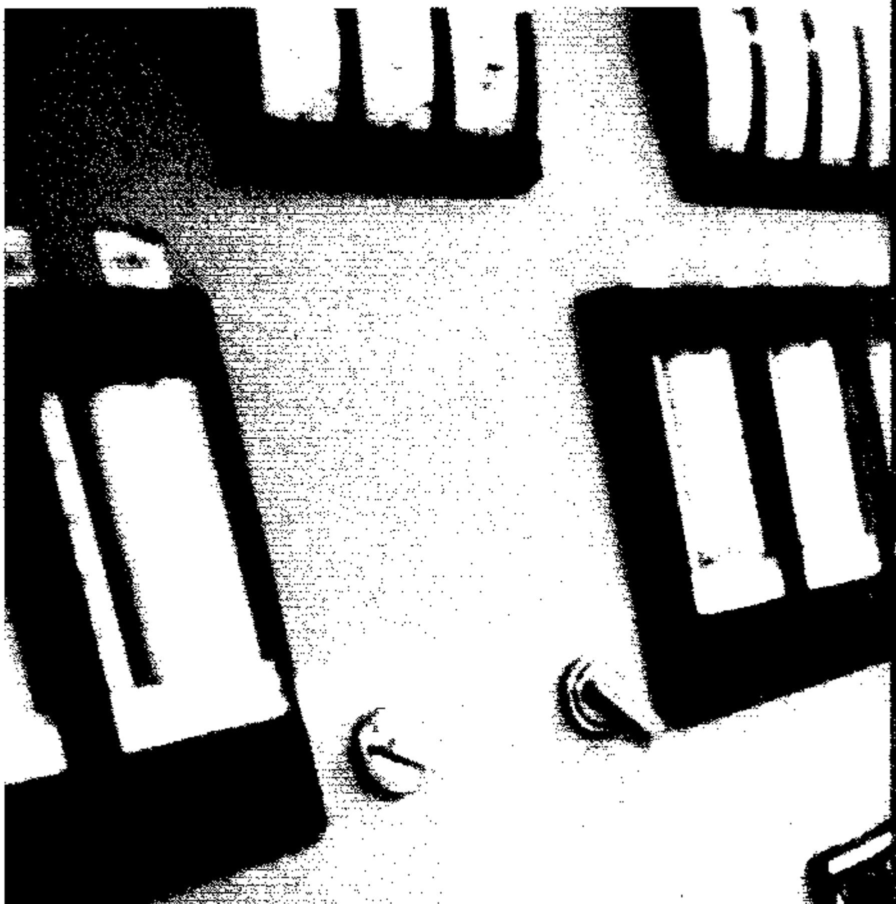
GCC plants will offer many advantages over power plants that burn coal directly to generate steam. They will achieve higher thermal efficiency (lower heat rate), making them economically competitive with other baseload generating options. They will meet emissions standards without serious penalty to plant efficiency and have potential for even lower emissions, if required. Land and water requirements will also be greatly reduced, helping to ease siting restrictions. In addition, GCC plants will respond readily to changes in electric power demand, making them suitable for daily load-following service.

The last-named feature, called maneuverability, was by no means a foregone conclusion. Oil- or gas-fired combined-cycle systems generally respond rapidly and can satisfy daily variations in electrical demand. But the performance of other interacting plant components (such as coal gasification reactors, acid gas absorption columns, and gaseous oxygen plants) had to be determined. In the normal commercial context of gas manufacture, gasification processes operate at a steady pace. It was necessary to show they can maneuver effectively when closely coupled with responsive combined-cycle systems.

To satisfy this important goal, EPRI initiated a program of transient-response studies at pilot plants and detailed simulations of integrated plant operation on

# Coupling a Gasifie

*Although combined-cycle power plants readily follow variations in load, coal gasifiers were originally designed for steady-state operation. How can these two systems be best linked and coordinated? The answers are coming from pilot gasifier test data and computerized control studies. It appears that fully integrated trains will be able to follow load, besides being cost-competitive for baseload service.*



computers. These verified that GCC plants can maneuver to meet load-following requirements. Such analyses are unique in that they established the dynamic performance and controllability of a future process technology well before its commercial development is complete.

The results of these studies are timely as baseline information for the design and operation of GCC plants, most prominently the 100-MW demonstration plant scheduled to come on-line early in 1984 for Southern California Edison Co. at its Cool Water station near Barstow, California. This $300 million project is jointly sponsored by EPRI, Bechtel Corp., General Electric Co., SCE, Texaco, Inc., and others yet to be announced. Its experience will confirm the load-following capabilities of GCC power plants.

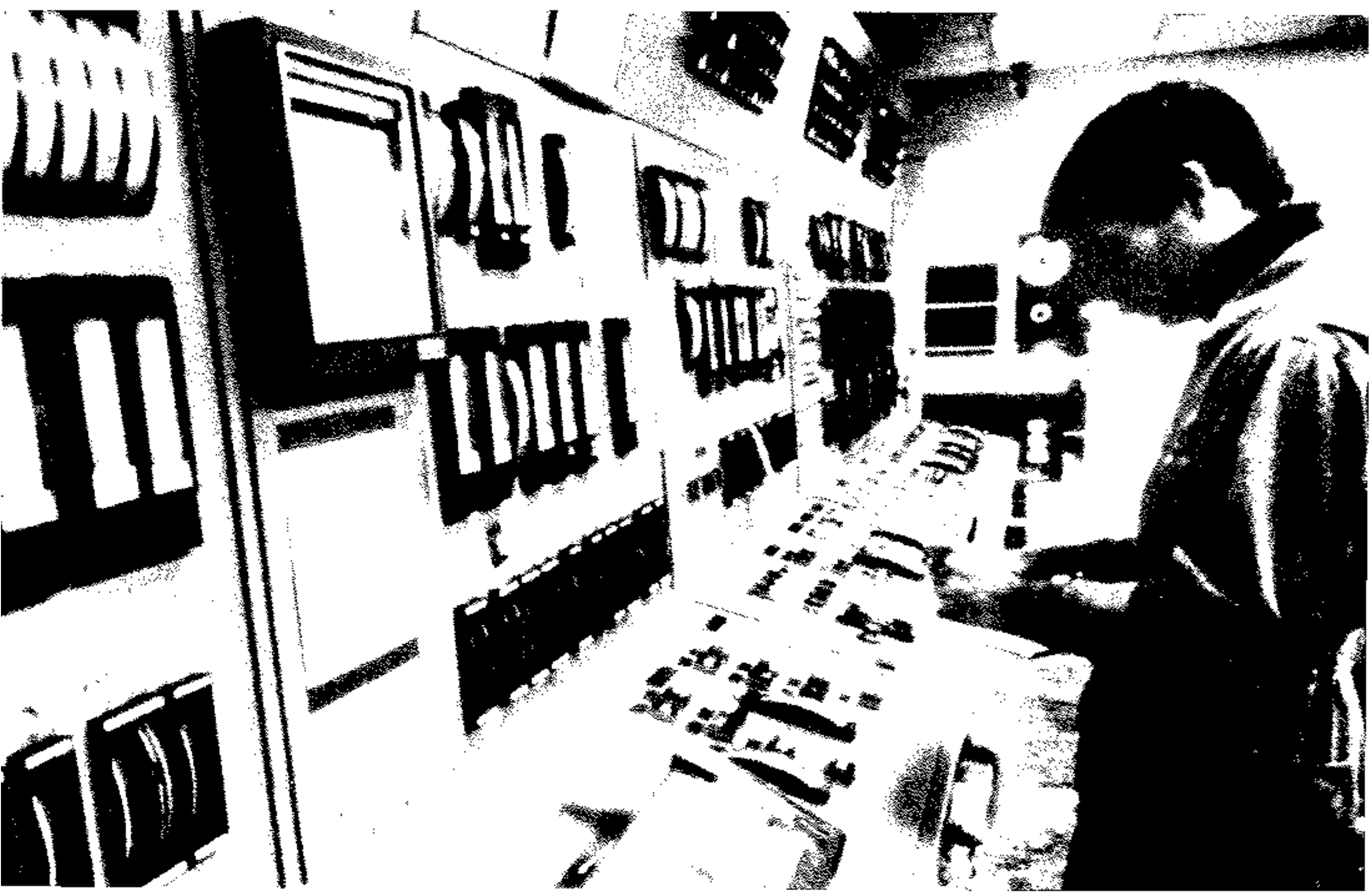
### Simulation variables

Large power plants have historically been designed for baseload service. As they age and become expensive to operate, they are relegated to daily cycling with lower annual capacity factors. Therefore, future plants must be flexible—specifically capable of cyclic operation.

It is difficult to set absolute requirements for the response rates of new power plants, but guidelines do exist and were used in the EPRI-sponsored control analyses. Ranges of values are recognized for different operating needs on interconnected power systems. The fastest response rates, 10–20% of unit capacity per minute, are for the very small changes involved in frequency regulation. The slowest rates, 2–5% per minute, are for the 20–40% load swings of daily load following. The guidelines call for a generation unit to be independently stable under all forms of control, controlled to within reasonable response limits, and able to assume a proportionate share of load- or frequency-regulating duty. The criteria imply that even baseload units must be prepared to vary electrical output; units that can load-follow effectively and economically will assume a larger share of the burden in the future.

GCC economic studies for electric power generation generally favor plants

# to a Combined-Cycle Plant



that produce medium-Btu fuel gas from oxygen-blown, pressurized, slagging gasifiers of the entrained-flow or moving-bed types. Accordingly, a series of transient-response tests were planned and conducted at three gasification pilot plants: a 15-t/d single-stage entrained-flow plant designed and built by Texaco at Montebello, California; a 165-t/d Texaco plant at Oberhausen, West Germany; and a 350-t/d moving-bed pilot plant owned by British Gas Corp. at Westfield, Scotland. (The last plant is basically a Lurgi, modified by BGC for operation at slagging temperatures.) The pilot test programs demonstrated excellent load-following characteristics.

The dynamic response of GCC plants was analyzed in separate simulation studies, also based on different gasifiers, conducted by two contractors. Entrained-flow GCC plant technology was simulated by Fluor Engineers and Constructors, Inc., with Westinghouse Electric Corp. as subcontractor. It was based directly on the Texaco process. Moving-bed GCC technology was simulated by General Electric, based on air-blown, dry-ash operation of a Lurgi-type reactor. In both cases, a full plant simulation was developed for use with a power system network model that portrayed the load patterns needed in evaluating GCC control strategies and capabilities. (In continuing work, General Electric is analyzing the dynamics and control of a GCC plant based on the BGC-Lurgi slagging gasifier in Scotland.)

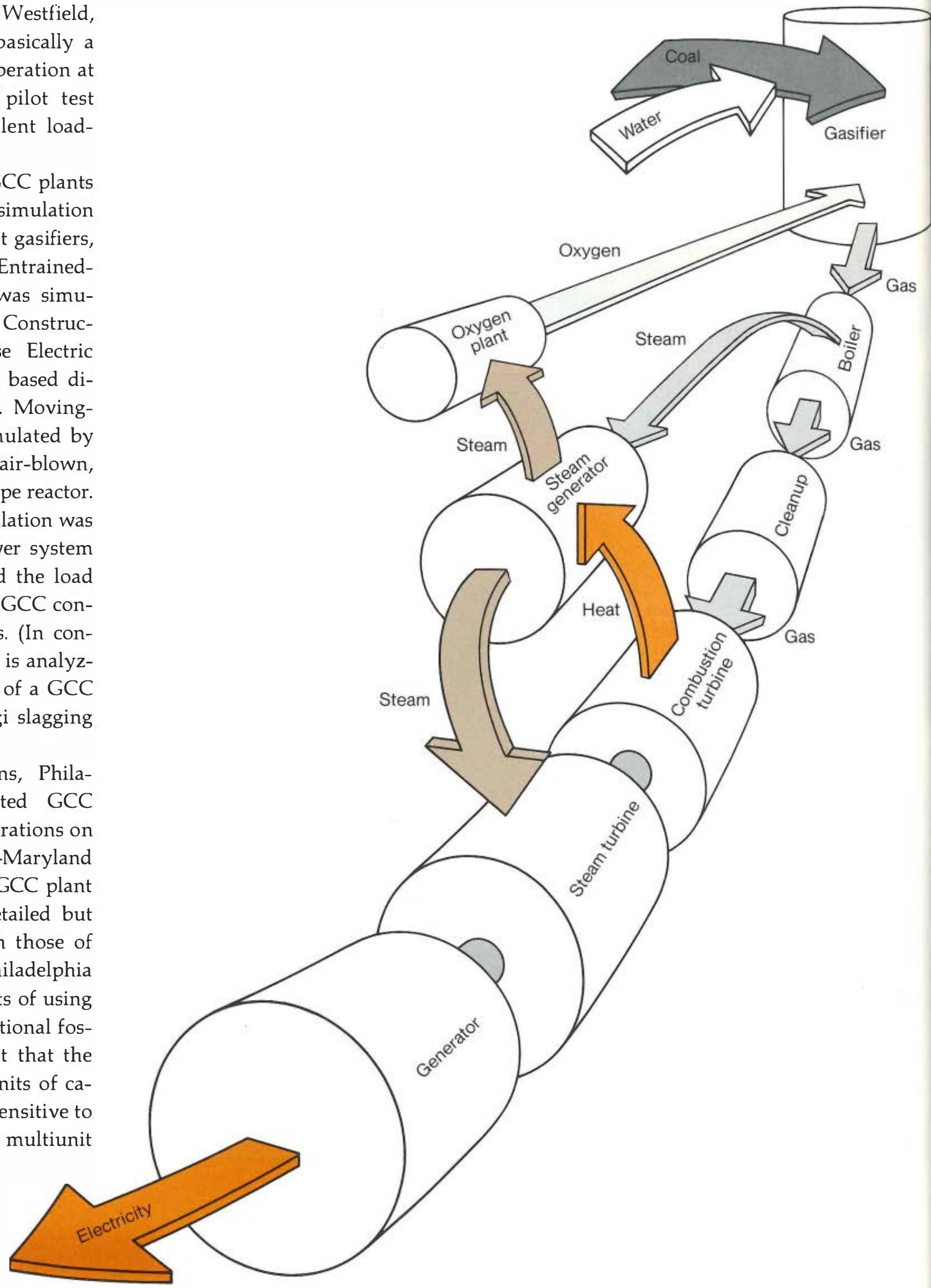
In more recent simulations, Philadelphia Electric Co. evaluated GCC plants in a model of actual operations on the Pennsylvania–New Jersey–Maryland interconnection. The utility's GCC plant models are somewhat less detailed but correlate reasonably well with those of General Electric and Fluor. Philadelphia Electric is examining the effects of using GCC plants in place of conventional fossil units. Early results suggest that the loading (the order in which units of capacity are brought on-line) is sensitive to the incremental cost curves of multiunit

GCC plant integration schemes are distinguished by the way that steam, air, oxygen, and heat are exchanged between units. Greatly simplified, these are the two plants analyzed in EPRI-sponsored computer simulations of load-following behavior.

The 354-MW entrained-flow gasifier is oxygen-fed and vaporizes water from the coal slurry feed to make its own reaction steam. The 205-MW moving-bed gasifier gets both air and steam from the combined-cycle power unit. The moving-bed gasifier requires considerably more stea to hold its process temperature below the slagging point; extracting this large steam flow from the combined-cycle unit reduces its net power output.

Energy throughput is proportionately greater for an oxygen-fed gasifier because its process stream lacks the large fraction of inert nitrogen found in air. (The product gas is therefore

OXYGEN-FED ENTRAINED-FLOW GASIFIER

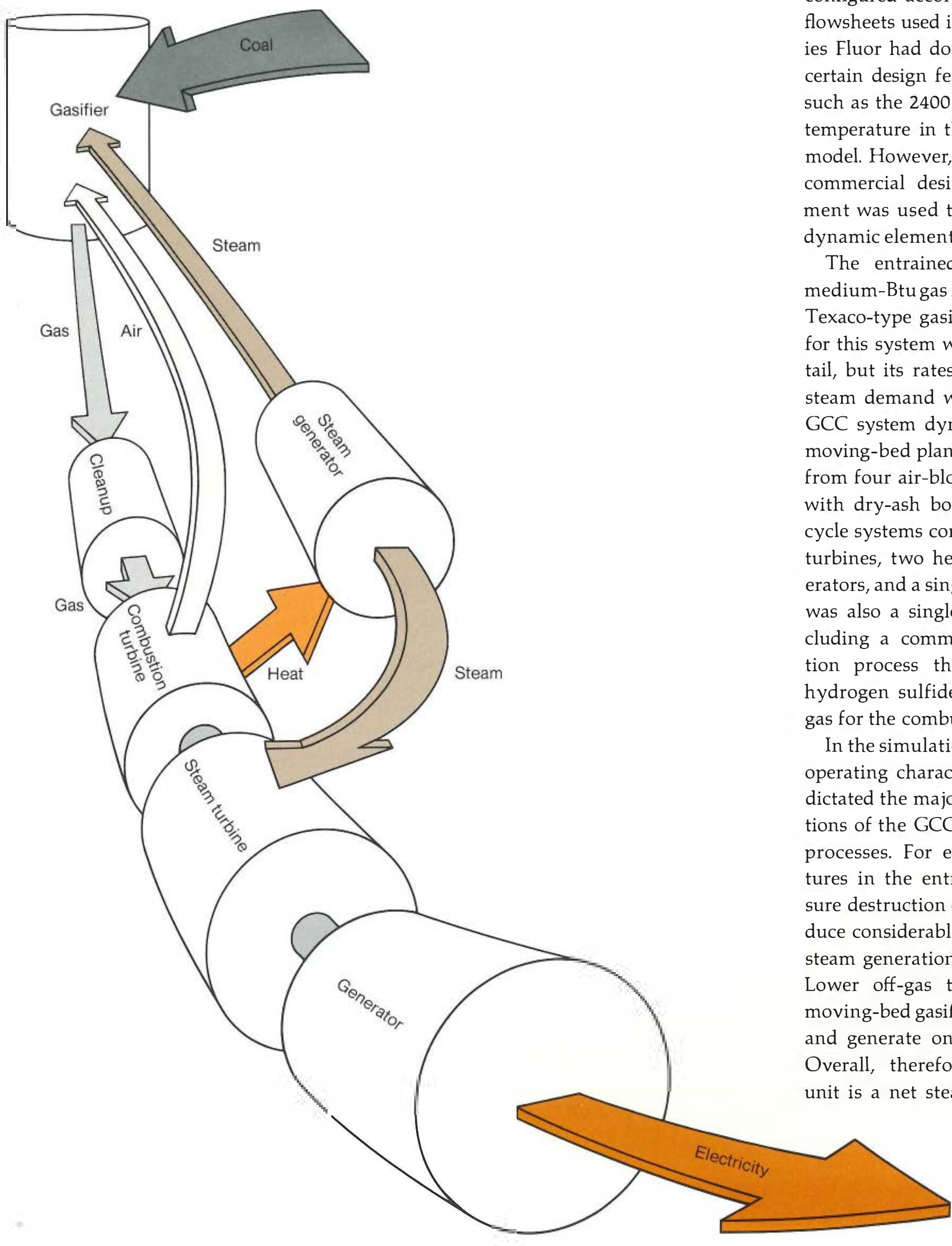


medium-Btu fuel instead of low-Btu fuel.) This factor results in a smaller volume passing through the gas cleanup unit.

Because the entrained-flow gasifier runs hotter (more than twice the nominal 1000°F, 540°C, of a moving-bed unit), the gas cooling necessary prior to sulfur removal yields significant heat to augment steam generation for the steam turbine. Thus, the ratios of combustion turbine to steam turbine capacity are about 2:1 for the 354-MW entrained-flow GCC plant and about 5:1 for the 205-MW moving-bed GCC plant.

Still under study, a third GCC configuration uses an oxygen-fed moving-bed gasifier modified for operation at slagging temperature. Its medium-Btu product and much lower steam consumption make for better capacity balance between the combustion turbine and steam turbine cycles.

AIR-FED MOVING-BED GASIFIER




plants. These costs are not accurately known because the technology is still under development; however, the model indicates that sequential loading of all units in a given GCC plant (before committing another plant) offers some advantage in response rate.

### Process assumptions

For the simulations the GCC plants were configured according to combined-cycle flowsheets used in earlier economic studies Fluor had done for EPRI. Therefore, certain design features were not typical, such as the 2400°F (1300°C) gas turbine temperature in the entrained-flow GCC model. However, in the absence of ready commercial designs, engineering judgment was used to determine the salient dynamic elements.

The entrained-flow plant produced medium-Btu gas from two oxygen-blown Texaco-type gasifiers. The oxygen plant for this system was not simulated in detail, but its rates of oxygen supply and steam demand were varied to influence GCC system dynamics realistically. The moving-bed plant generated low-Btu gas from four air-blown Lurgi-type gasifiers with dry-ash bottoms. Both combined-cycle systems contained two combustion turbines, two heat-recovery steam generators, and a single steam turbine. There was also a single gas cleanup train, including a commercial physical absorption process that selectively removes hydrogen sulfide and yields clean fuel gas for the combustion turbines.

In the simulations, as in the real world, operating characteristics of the gasifiers dictated the major differences in integrations of the GCC plant components and processes. For example, high temperatures in the entrained-flow gasifier ensure destruction of tars and oils and produce considerable heat for high-pressure steam generation in a waste-heat boiler. Lower off-gas temperatures from the moving-bed gasifier result in tars and oils and generate only low-pressure steam. Overall, therefore, the entrained-flow unit is a net steam producer, while the

Load reduction produces distinctive response patterns in the components of entrained-flow and moving-bed GCC plants. These examples illustrate gasifier-lead control and turbine-lead control, respectively. The entrained-flow GCC curves would not change greatly if the control strategies were transposed, but the moving-bed GCC curves would reveal a slower, less stable response.

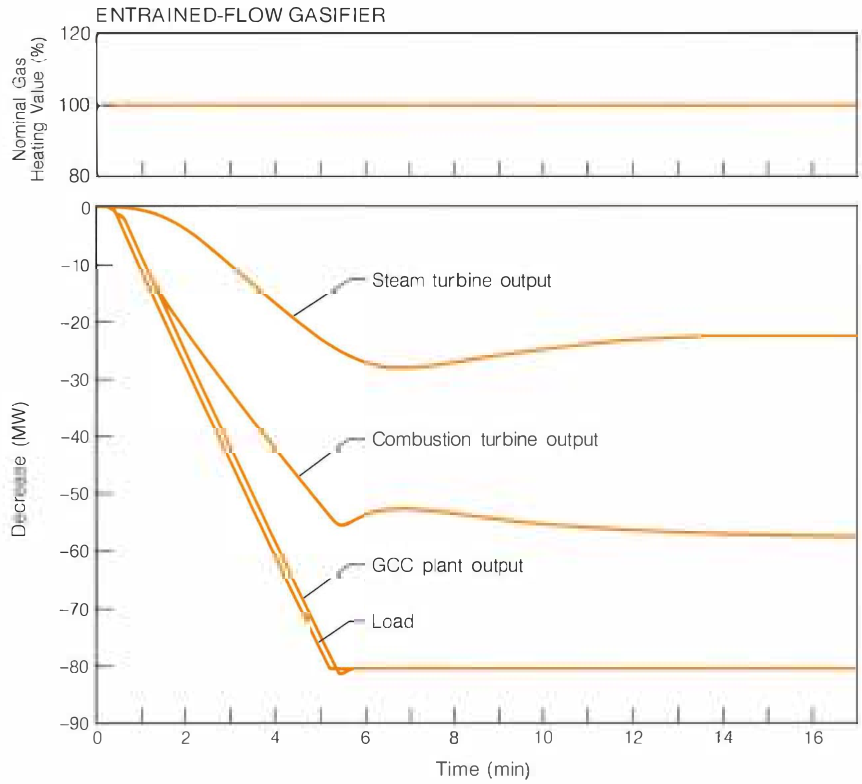
In the 354-MW entrained-flow example, load is ramped down at 4%/min, bringing the plant output down by 80 MW (combustion 57 MW, steam 23 MW). There is a uniform time lag as plant output follows load downward. The plant overshoots slightly at the bottom (about 5.5 min), but the combustion turbine compensates for inertia in the steam turbine response, and within about 10 min the plant is nearly settled at its reduced output level.

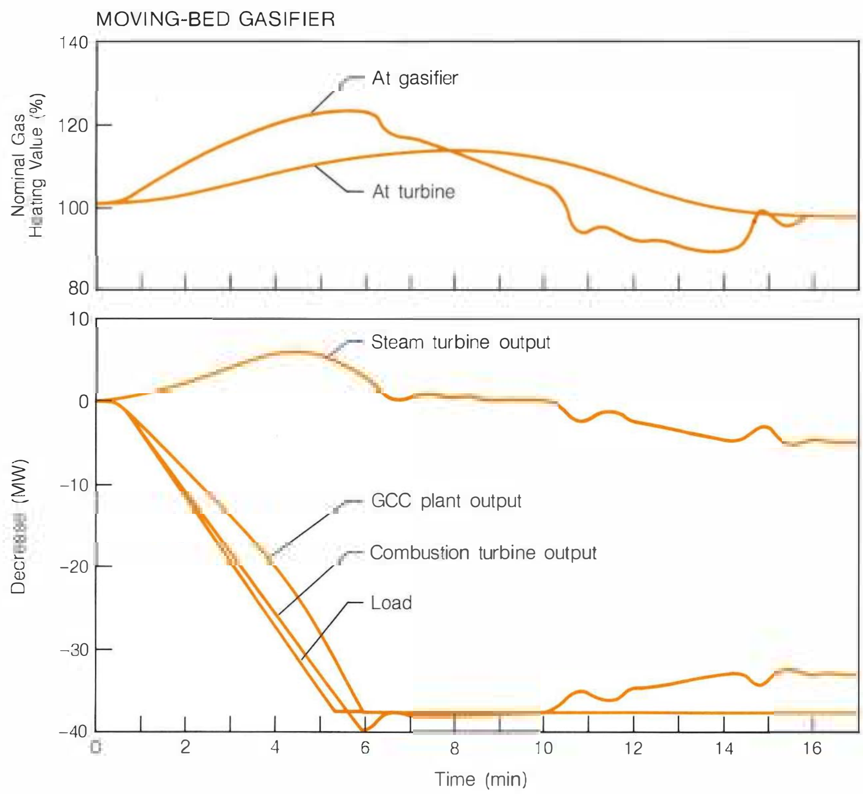
The heating value of the gas (measured at the gasifier exit and, after cleanup, at the turbine inlet) is steady throughout the load change. This is inherent in the entrained-flow process and is the key to the straightforward, unwavering overall response of this GCC plant.

In contrast, when steam and air flows to the moving-bed gasifier are reduced during a turndown of the 205-MW GCC plant, the responses of both turbine cycles are distinctly affected. In this case, the 4% ramp rate cuts plant output by 37 MW (combustion 33 MW, steam 4 MW).

The extra steam momentarily available to the steam turbine causes its output to increase. The plant output proceeds down a slower ramp, and the combustion turbine overshoots its ultimate reduction. Simultaneously, the gasifier production is temporarily enriched (more methane) as coal continues to devolatilize from the hot bed, but with less diluent air and steam.

Thus gas with a higher heating value ultimately (about 7–10 min) reaches the combustion turbine, countering its move toward reduced output. (The brief but very pronounced fluctuations in the curves for this plant occur when some fuel gas must be used to pressurize the coal feed lockhopper.) Stable operation is achieved after about 16 min.



moving-bed unit is a large steam consumer. This directly affects fuel system integration, which, in turn, affects plant response.

The entrained-flow GCC plant offers a higher steam-turbine electrical output because it has additional steam produced in the waste-heat boiler. Conversely, the moving-bed plant requires a large extraction steam flow for the gasifier, resulting in a low steam-turbine electrical output.

Dynamic performance of the two gasifiers is also markedly different. The entrained-flow reactor is capable of large step changes in throughput (coal in, gas out), while holding relatively constant fuel gas temperature, composition, and heating value. This has been substantiated by Texaco's pilot plant tests at Montebello and Oberhausen. By comparison, fuel gas from the air-blown Lurgi-type unit varies widely in heating value during transients. For example, if combustion turbine fuel gas is cut back to follow a lower load, automatic pressure controls immediately reduce the air and steam flows to the gasifier. There is a sudden drop in overall fluid flow in the reaction bed, yet the evolution of volatile hydrocarbons at the top is momentarily unchanged—hence there is a transient increase in heating value. This tends to counter the earlier throttling down; it is thus a positive feedback effect and hampers stable control. Also, in the moving-bed gasifier the gas pressure in the outlet header may drop when the feed coal lockhoppers are being pressurized. This causes variations in the coal devolatilization rate and gas heating value. Comparable effects are not encountered in the entrained-flow gasifier because its coal feed is continuous and the residence time is short.

### Subsystems and controls

For purposes of gas cleanup, a packed-column absorber was simulated in these studies, but without a regenerator column or auxiliary equipment. A generalized simulation model of a complete hydrogen sulfide absorption system is being developed, and its dynamics will be examined in detail.

One important finding of the Fluor-Westinghouse simulation was a potentially large mismatch in the rate of change for the entrained-flow gasifier and its oxygen plant. In that model, the partially simulated oxygen plant was permitted only the slow rate of change (10–25% of baseload production per hour) considered typical from earlier experience with high-purity oxygen plant designs. However, later information sheds new light on this point. At EPRI's behest, Air Products & Chemicals, Inc., recently conducted transient-response tests on a 1000-t/d commercial high-purity oxygen plant. Closed-loop computer control was used to attain rates of change fully consistent with the highest rates (10% per minute) expected in an integrated GCC plant.

EPRI's contractors evaluated two basically different GCC control modes, turbine-lead and gasifier-lead. The former is a familiar power plant control strategy: the combustion turbine fuel inlet valve moves in response to changing load on the power system, and the fuel gas flow is regulated accordingly by pressure control of the gasifier feed streams. In the gasifier-lead mode, the gasifier feed valves first respond to changing load, and the combustion turbine valve subsequently responds to pressure control.

Review of both simulations under the two control modes permits some general conclusions. Closed-loop operation was successful in both plants, because the combustion turbines responded rapidly and effectively handled much of the burden.

The fast response rate of the entrained-flow gasifiers, with constant gas heating value, makes this option very suitable for closely coupled operation in a GCC plant. As a result, the entrained-flow plant demonstrated excellent capability for cyclic operation to meet power system needs. Both control modes worked well in closed-loop operation of this overall plant during normal transients and during emergencies after the simulated loss of key components.

As expected, the response rate of the moving-bed gasifiers was slower because of the larger reacting masses of coal. Transient changes in fuel gas heating value also made control of these gasifiers more complex. Operation of the combined-cycle plant, in turn, was accompanied by fuel system transients that inevitably limited the closed-loop response rate during load-changing operations. Nevertheless, in the turbine-lead control mode, this plant was controlled satisfactorily to meet load-following criteria. In the gasifier-lead mode it was less responsive, making this mode less acceptable.

Perhaps the most significant conclusion from these analyses was that both the entrained-flow and the moving-bed GCC plants are capable of closely coupled operation without interposed gas storage buffers or supplementary fuels. On the basis of these simulation studies and the associated experimental work with pilot gasifiers, the load-following maneuverability of GCC plants has now been thoroughly established. Detailed design of the 100-MW Cool Water demonstration plant is proceeding with improved confidence. ■

### Further reading


*Economic Studies of Coal Gasification–Combined-Cycle Systems for Electric Power Generation.* Final report for RP239, prepared by Fluor Engineers and Constructors, Inc., January 1978. EPRI AF-642.

*Entrained-Gasification–Combined-Cycle Control Study.* Final report for RP913-1, prepared by Fluor Engineers and Constructors, Inc., and Westinghouse Electric Corp., June–July 1980. EPRI AP-1422 (3 vols.).

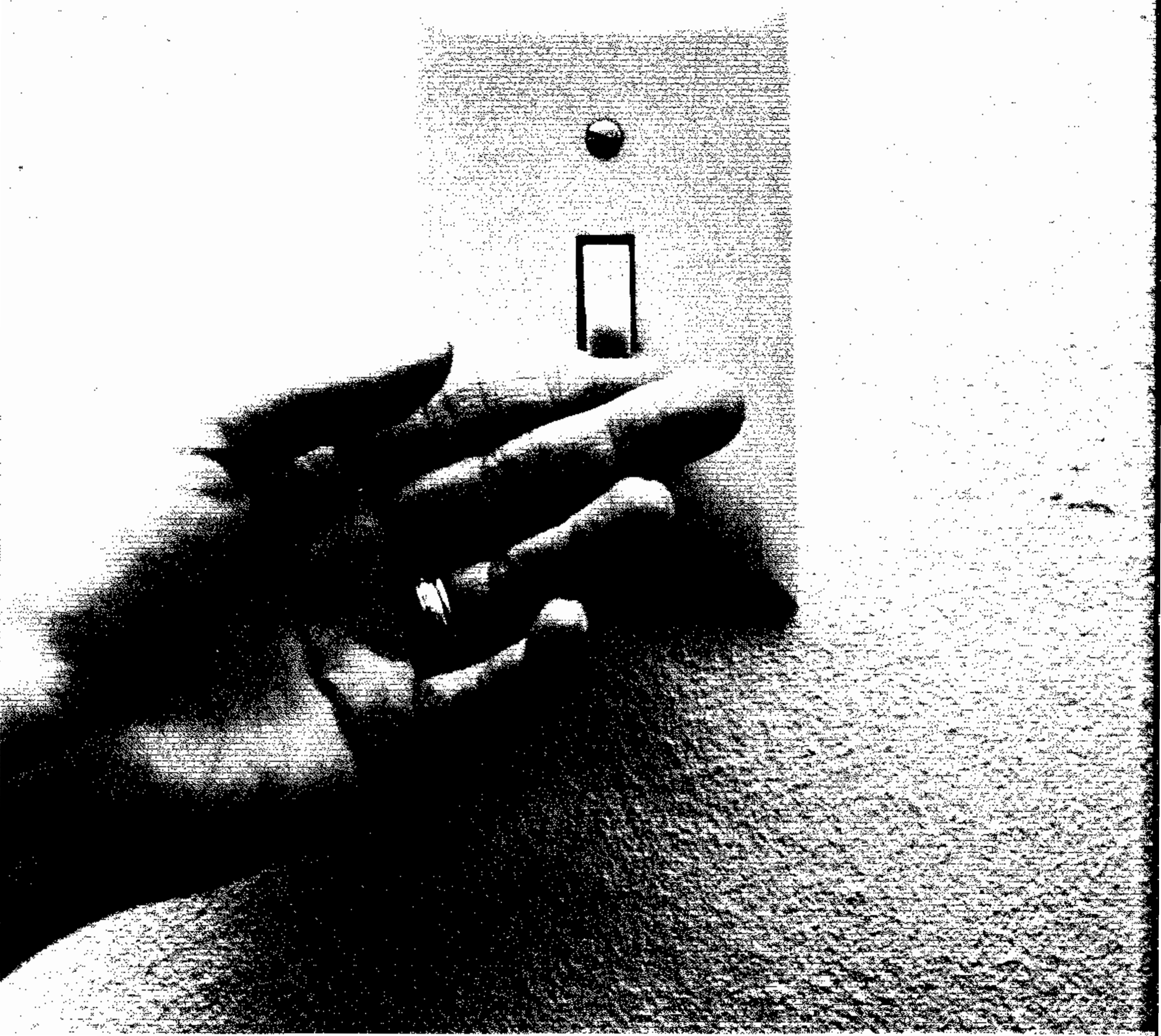
D. Ewart et al. "Power Response Requirements for Electric Utility Generating Units." In *Proceedings of 1978 American Power Conference,* Vol. 40, pp. 1139-1150.

*Preliminary Design Study for an Integrated Coal Gasification–Combined-Cycle Power Plant.* Final report for RP986-4, prepared by Southern California Edison Co., August 1978. EPRI AF-880.


This article, edited by Ralph Whitaker, is based on a paper presented by George Quentin, Advanced Power Systems Division, at the Engineering Foundation Conference on Process Control, Sea Island, Georgia, January 1981.

New energy supply options that draw on large-scale domestic resources will take years to demonstrate and deploy. If these are to be made available by the 1990s, critical choices must be made now.

# ENERGY CHOICES: SCARCITY OR ABUNDANCE



Government policy and public debate about the energy crisis have concentrated for nearly a decade on how the United States can reduce its oil imports. Particular emphasis has been placed on lowering overall energy demand in the near term, while long-range opportunities for increasing energy supplies have often been ignored. This perspective may now be changing. "Potentials are really quite promising for the long run," says Sam Schurr, deputy director of EPRI's Energy Study Center. Energy scarcity or abundance is ultimately a matter of choice, and Schurr calls attention to the fact that impulses arising from the energy supply side have been an important dynamic force shaping American history.

Indeed, future historians may look back on the current crisis as just another in a long line of energy transitions. Consider, for example, the substitution of coke for charcoal in blast furnaces during the eighteenth and nineteenth centuries. The emerging American iron industry was highly decentralized because of its dependence on charcoal, which is a wood product. Charcoal was consumed in large quantities and its sources were widely separated geographically. Forests around early mill towns were quickly decimated in the effort to supply charcoal for blast furnaces and wood for locomotives. And as forests dwindled, wood became increasingly expensive.

In addition, charcoal rapidly disintegrated when it was transported. Because charcoal was readily crushed and was thus incapable of supporting a heavy charge of iron ore, the furnaces had to be rather small. The average annual output of British blast furnaces in the early eighteenth century, for example, was only about 300 tons.

Coal as it came from the ground was a poor substitute for charcoal because its impurities could ruin the quality of the iron produced. Development of the coking process and redesign of furnaces supplied the opportunity to use this abundant fuel and thus provided a critical energy resource to the industry. In addition, the use of stronger coal permitted heavier charges of iron and subsequently, an increase in the size of furnaces. As Nathan Rosenberg, an economic historian at Stanford University, described it at a recent EPRI workshop on productivity, "The physical characteristics of the new fuel—its greater hardness and strength—provided the basis for a transformation in metallurgical technology that was to extend over two centuries: the growth in furnace size and the related improvements in fuel efficiency that depended on that growth. These developments could not have occurred in a charcoal system, however abundant the charcoal."

### The next transition

Now that one of our own primary fuels—petroleum—has become too expensive, scarce, and unreliable to meet future needs, what can we say about the next energy transition? Chauncey Starr, director of the Energy Study Center and vice chairman of EPRI, points out that accelerated electricity production from solid fuel—coal and nuclear—could profoundly reduce U.S. vulnerability to imported oil. About 35% of total oil consumption is used for some form of heat, including utility boilers, which could be replaced by electricity generated from other fuels. "Even if only half the maximum potential is achieved," Starr concludes, "we will be in a position to completely displace Middle East sources."

The most obvious place to begin substitution would be to replace oil-fired power plants, which use the equivalent of 20% of U.S. oil imports, and gas-fired plants, which use the energy equivalent of 28% of imported oil. Only 8% of the oil and 3% of the natural gas are used for peaking generators, where these fuels have unique advantages. Thus shifting from oil and gas, except for peaking needs, could displace roughly all Middle East imports.

"To place this possibility in context," Starr explains, "the present utility plans for new solid-fuel stations to come online this coming decade total 215 GW (e) of capacity. This should be compared to the additional 50 GW (e) needed to replace oil-based plants and 70 GW (e) to replace gas." Starr concludes that if space, water heating, and industrial heat applications of oil are also included, all OPEC imports could be displaced.

Further displacement of imported oil may come from two other sources. First, American oil shale reserves are quite large and offer the potential for eventually replacing all oil imports. Costs are higher than those for oil from naturally flowing wells, but near-term commercialization of the recovery process is now considered within reach. What is needed is a large-scale demonstration to settle various ancillary uncertainties: environmental issues, equipment reliability, fuel-refining variables, and so forth. Second, coal conversion to liquids and gases is technically feasible, but large-scale engineering development remains to be accomplished. This might be done during the coming decade if proposed projects are started soon.

This emphasis on time is particularly critical when it comes to increasing the supply of energy. Eight to 10 years is now required (from commitment to availability) to bring a new coal-fired power plant on-line. About half that time is used for the approval chain. Coal conversion and oil shale technologies will take even longer to have substantial commercial impact because of the time required for large-scale demonstration. Nuclear plants, which represented about half of all planned capacity in the United States, have been caught in a de facto moratorium in the wake of Three Mile Island. Clearly, if new energy supply options are to be available by the 1990s, critical choices must be made quickly.

Over the short term, at least, conservation will be critical. Important savings can be realized in energy use for automobiles and residential heating, which together account for about one-fourth of the nation's total energy demand. By the turn of the century, according to a study conducted by Resources for the Future, Inc., average fuel efficiency of automobiles in use could about double, so even with substantially more cars on the road, total gasoline consumption by automobiles should decline by 30%. Similarly, as better-insulated houses are built and outfitted with more efficient heating systems, total energy used in home heating should also drop.

Even with conservation, substantial energy growth will be required in the productive sectors of the economy to create jobs for an expanding workforce. To achieve an assumed GNP growth rate of 3.2% a year will require average annual energy growth of about 1.8%, according to the same study. That would mean a cumulative consumption during the last quarter of this century of 2500 quads ($2.5 \times 10^{18}$ Btu) of energy, equivalent to considerably more than all the estimated remaining recoverable domestic resources of conventional oil and natural gas, conservatively estimated. (One quad is roughly equivalent to the energy released from burning one-half million barrels of oil a day for a year. In 1976 the United States consumed 75 quads [$75 \times 10^{15}$ Btu]; in the year 2000, under the above conditions, 115 quads would be required.)

A large expansion in those domestic energy supplies for which resources are abundant is therefore going to be necessary. And with an eye to the important historical links between abundant, low-cost energy supplies and the general forward movement of the American economy, Schurr urges a high policy priority be given "to selecting and developing those supply technologies that will keep energy costs as low as possible."

Supply expansion, however, has been difficult to achieve, according to Starr, because energy discussions in the last decade have been permeated by conflicting philosophical viewpoints. On one side were those who believed in "diminished objectives," arguing that environmental degradation and declining oil reserves were signals marking the limits of industrial expansion. The proposed way to accommodate limited economic growth without causing severe unemployment was to substitute labor for energy as a means of production. The opposing side favored "more effective use of resources," pushing to continue industrial expansion within the limits set by changing circumstances. Their way of achieving this was to use more domestically available sources of energy, including coal and nuclear power.

This fundamental argument, Starr asserts, will be resolved by a gradual series of public decisions, including the response to issues raised in the recent national election. As a result, a climate is being created in which the problems of inflation and unemployment will likely be addressed through government policies aimed at improving supply and productivity.

What will it all cost? No definitive answer can now be given to this question, but a variety of factors influencing the costs and benefits of a supply-side approach are worth noting. Clearly, the size of the task ahead is awesome. From 1963 to 1973, U.S. capital stock grew twice as fast as the labor force. Then from 1973 to 1979, both grew at virtually the same rate. Throughout the national economy there has thus been a significant falling off of investment, which must now be corrected if productivity is going to rise.

The situation is particularly critical in the energy sector of the economy, which now accounts for about 20% of total gross investment from private domestic sources. This fraction is projected to rise, under "business as usual" assumptions, to about 25% by 1990. Despite major capital investment in new domestic supplies, such as the Alaska pipeline and a number of nuclear power plants, domestic energy production increased by less than 3% between 1970 and 1979. To greatly reduce reliance on foreign oil will require a substantial increase in the investment funds going into domestic supply expansion.

Fortunately, the payoffs of this investment will also be great, both in simple monetary terms and in a greatly decreased vulnerability to the international oil cartel. In addition, such investments could lead to a new era of energy abundance from domestic resources at tolerable economic and environmental costs. Developing new and improved technologies for using domestic coal, uranium, and shale resources, Schurr argues, could eventually change the fundamental cost characteristics of energy supplies—making them act less like imminently depletable commodities and more like reproducible manufactured products.

The reasons are twofold: First, naturally occurring reserves of these solid fuels are many times greater than the cumulative energy consumption needed to take the United States well into the next century. Second, if breeder reactors are fully developed, the cost of raw uranium could become a vanishingly small component of the cost of producing electricity. Coal conversion and oil shale extraction could also eventually place a ceiling on the cost of oil and gas.

"After technologies of this type mature," Schurr concludes, "their long-run cost profiles are quite likely to take the general form of a plateau at a real level, estimated at no more than about twice the prices in the late 1970s for liquids and gases and even lower in the case of electricity." Meanwhile, the cost of natural petroleum and gas products can be expected to continue to rise sharply over time if demand continues to rise.

### U.S. policy and world economy

The devastating effect of high oil prices on the world economy has reminded all nations of their growing interdependence, and U.S. energy choices must take this into account. The argument is sometimes made that expanding America's domestic energy supply would exacerbate the divisions that already exist between the rich and poor nations of the world. Schurr points out, however, that most developing nations cannot afford the capital investments necessary to make the type of energy transition now in prospect for the United States. Nor do they have the industrial infrastructure compatible with the larger power-generating technologies. They will, therefore, depend on petroleum for a considerable time. Any decrease the United States can achieve in its oil imports by substituting domestic energy resources should thus help the developing countries by easing pressure on the international petroleum market.

Schurr concludes: "If one takes seriously the need for accelerating the growth of the developing countries, one argues for maximum international efficiency in the production of all goods." There is a global need for rapid growth in both developed and developing countries, with each group emphasizing the type of production it can tackle with greatest efficiency.

Starr declares it is also necessary to ask what would happen if the United States refused to aggressively develop its energy resources while the rest of the world pursues expansion. This is already happening to nuclear power, with potentially disastrous consequences. "We are considered to be so uncertain as to national intent as to be excluded from real policy discussions. As a result, we shall soon be in the position of importing nuclear equipment that has been demonstrated abroad, based on technology originated years ago in United States laboratories and production plants."

This technology lag could become even more significant as the relative importance of electricity grows. A shift toward electricity is likely to be a crucial part of the larger effort to increase productivity because of electricity's unequaled ability to speed automation. New microprocessor technology will increase that ability even further. Consumer preference for electricity as a clean, efficient energy source has been clearly demonstrated in recent years, and increased electrification of industry is already the official policy among some of America's most aggressive trading partners.

At present, almost one-third of the U.S. primary fuel equivalent is used for the generation of electricity. By the year 2000, EPRI studies show that this proportion will probably rise to one-half. This shift will help raise productivity in industry, and by using domestic energy resources, electricity generation can help the country save more money than the simple price of imported oil would indicate. Studies by Alan S. Manne of Stanford University show that the public value of not importing a single barrel of oil may be as high as $75, although its actual price may be only half that much. The reason is that external costs of imports are not always reflected in market prices. For example, there are additional expenditures that must be made to ensure against supply interruptions. And the possibility of military intervention in the Middle East, although not directly quantifiable as a specific price, has nevertheless contributed to increased defense expenditures and thus to the social cost of imported oil.

Although the potential for expanding the U.S. energy supply is far more hopeful than many people realize, great uncertainties remain over whether the public is ready to make the critical choices needed to bring it about. "There are persistent concerns about possible catastrophic threats from supply technologies," Schurr says. "Even if the possibilities are slight (as they appear to be) that disasters will occur, the effects of 'worst cases' (if they materialize) could be devastating. On the other hand, national and international institutional and technical approaches exist for reducing many of the remaining risks to acceptable levels. It is of the utmost urgency that these approaches be vigorously pursued.

"In addition, there must be a major and continuing effort to keep the public fully informed on what is being done and on the prospective outcomes of these actions, because public acceptance may be the critical issue. The fundamental choice," Schurr concludes, "is a stark one—it is between accepting and accommodating to energy scarcity (the position until now) or setting out to achieve energy abundance (a feasible long-run goal)." ■

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This article was written by John Douglas, science writer. Technical background information was provided by the staff of the Energy Study Center.

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# Cost-Sharing Energy Development

In exchange for a percentage of net sales from the developed product, the government is now cost-sharing R&D on new energy technologies with industry. DOE's power to waive patent rights makes this expanded cooperation possible.

During its 204-year history, the federal government has played many roles in relation to promising new technologies. For most of those years, its principal role has been patron of the sciences and what the framers of the Constitution called the useful arts. Had it not been for generous federal subsidies, for example, railroads, telegraph, and commercial airline service would have developed at a far different pace.

Since the start of World War II, the government has often promoted technological change through its own purchase of sophisticated goods and services —a role that led to the availability of such important parts of everyday life as jet airliners and integrated circuits.

For the past four years, another role has been emerging—that of federal government as venture capitalist. Like the fabled venture capital funds that made and lost fortunes invested in high-risk technology-oriented firms along Route 28 near Boston and in Silicon Valley in the San Francisco Bay Area, several program offices in the Department of Energy are bankrolling firms with new ideas that promise to help in reducing the nation's energy problems. And in the process, they may be developing mechanisms for industry-government cooperation that will serve the nation well in the future.

## Unique Patent Waiver Powers

Experience has taught government officials that a key obstacle to doing business with the best R&D performers is their general unwillingness to give up rights to their inventions in return for federal dollars. "We're dealing with an entirely different clientele here," says Douglas G. Harvey, the director of DOE's Office of Industrial Programs, a part of its conservation and solar energy organization. "Unlike Department of Defense and most NASA programs, we are purchasing technologies for which the government has very little use. The products and processes we are funding are for the benefit of the commercial sector.

"They are not like a new airplane wing the government needs," he continues. "Patent rights to these inventions represent an asset with significant value in the marketplace. And clearly, if a patent represents an asset, industry is not going to give it away." (Most federal agencies require firms to give up rights to inventions supported with federal funds.)

Harvey and a number of other DOE program managers, however, are willing to routinely protect industry's patents, data, and other intellectual property by using novel patent waiver powers granted to DOE by the 1974 law creating the Energy Research and Development Administration (ERDA). But in return for a quo, they are demanding a quid—the recoupment of at least a portion of the federal investment in commercially successful development efforts and the as-

Harvey

surance that the technology will be available to industry through licensing at a reasonable royalty.

The R&D cycle takes years to complete, so it will be several years before the wisdom of many of these high-risk, high-potential ventures can be gauged. But if, as many assert, the strength of a contract research program can best be measured by the strength of its performers, several DOE organizations are running first-class programs.

For example, Harvey says, "We're now providing venture capital to establish a marketplace for an advanced technology that will convert waste heat into electricity, a new process that has never before been used in industry." One of its industrial partners in this venture is the Sundstrand Corp., which is receiving $3 million to support the manufacture of the first 10 organic Rankine bottoming-cycle units. The 600-kW units are being installed to recover factory waste heat formerly rejected into the atmosphere. If the units are a commercial success, Sundstrand will pay DOE a $20,000 fee for each unit it sells until DOE's investment in the technology is recovered.

## Recouping the Federal Investment

The Office of Industrial Programs is certainly a leader in launching ventures of this sort, but it is not alone. DOE's Office of Advanced Technology Projects—an arm of its energy research organization—has entered into a venture with Texas Instruments, Inc. (TI) to develop a second-generation photovoltaic system for producing electricity on the roofs of load centers. The technology uses silicon microspheres, some of which have a surplus of electrons in their crystalline lattice and others, a deficit. When these spheres are immersed in an electrolyte such as hydrogen bromide in the presence of sunlight, hydrogen gas is produced, explains Ernest F. Blase, the director of the office.

Blase

The spheres should be far cheaper to produce than monocrystalline silicon photovoltaic cells. An additional advantage to the spheres is that the hydrogen produced can be easily stored and converted into electricity by a fuel cell. Generation can thus be matched with demand throughout the day. TI says its first commercial units will appear in 1985. Under the cooperative agreement between DOE and the company, TI contributes $4 million of the cost of the three-year project and DOE pays the remaining $14 million; the industry's cost share is far in excess of that found in most government-sponsored photovoltaics projects.

TI insisted on retaining rights to the invention before it would enter into an agreement with the government, a condition that DOE accepted. In return for this waiver, DOE worked out a deal whereby it will receive a royalty equal to 1% of net sales of the units and 33⅓% of royalties resulting from the licensing of patents and technical data developed under the agreement. The royalties will continue to be paid until the government recoups its investment in the technology.

Blase, whose office is chartered to fund the development of high-risk technologies having the potential to make large contributions to the nation's energy supply, has since used the TI contract several times as a prototype for other new ventures. Recently, his office negotiated a contract with Duracell Products Co., Inc., for the development of a room-temperature rechargeable lithium battery for use in electric vehicles and utility load leveling.

According to the claims of the manufacturer, the battery would have many times the energy density of cells developed up to this time, and if successful, the proposed battery would allow a four-passenger vehicle to go 300 miles at highway speeds before recharging. The company had already spent \$2–\$3 million "getting the science for the battery in place" at the time the contract was being negotiated, Blase says.

Once again, in return for recoupment and cost-sharing, DOE granted a patent waiver to Duracell. DOE patent waivers typically require companies to either meet the need for their invention or license it to responsible parties. DOE also reserves the right to take over patents that are not put to reasonable use.

"I really feel the Duracell people would not have come to the federal government unless we were able to offer these kind of considerations," says Blase. He adds, "In other than DOD business, companies that have a strong proprietary interest in certain technologies are reluctant to come to the government for support because they feel they run the risk of losing the intellectual property and patent positions they have developed."

Now that DOE has developed a formula for protecting proprietary positions, "we feel we can persuade companies to come forward with their better research ideas," Blase explains.

### Recovering More Than Expended

DOE's formula that cost-sharing plus recoupment equals a patent waiver, however, is not set in concrete. Lately, in fact, the government has been holding out for a genuine piece of the action.

In one of the latest ventures in the Office of Advanced Technology Projects, DOE's partner—IIT Research Institute—was seeking the highest level of government commitment possible for a novel oil shale processing technology that uses radio frequency radiation to retort shale underground. DOE, as usual, was seeking the best possible deal for the government.

The final agreement calls for DOE to recover 20% of gross royalties from the licensing and sale and the income from the use of the technology until a certain amount of money is recovered. If the government contributes \$5 million or less to the development effort, it will recover its initial investment in the technology. As the government's share increases to over \$10 million, the recovery amount increases to two times the government funds expended.

And this may be only the beginning; there are indications that in future contracts DOE will begin to hold out for a continuing percentage of the sales and licensing revenues from inventions in return for funding support, a development that does not please all DOE program managers. DOE should sponsor technologies to gain their earliest possible introduction, not to secure the highest possible return on investment, one senior DOE official says. He argues that if it decides to hold out for recoupment plus a piece of the action, the pace of commercialization of many exciting new technologies could be slowed.

All is not sweetness and light when it comes to waiving the government's rights to inventions made with federal support. Blase and DOE's Office of General Counsel, for example, spent untold hours in 1980 defending the grant of a patent waiver to Mobil Oil Co. for a process to convert methanol into gasoline. DOE and its predecessor agencies had invested money in the catalytic process, known as the M-Gasoline process, early in its development cycle. Last year, this came under heavy attack from Rep. Berkley Bedell (D-Iowa), the chairman of a House small business subcommittee, for not protecting the public's interest in this technology.

Blase, however, is philosophical about the attack. "There is a certain kind of vulnerability attached to this kind of operation. You run the risk that there may be misunderstandings about the motivation for your actions." He points out that Mobil has 40 background patents in areas related to the M-Gasoline process.

"The technology is already here, but if we are interested enough, we could spend tens of millions of dollars reinventing the catalyst," he says. "The danger is that if we are not careful, the companies that have the strong proprietary position won't do the work. What I am arguing for is to establish some way for industry and government to work together."

Also needed, he adds, are new models for government, small business, and venture capital cooperation. "Once we have established a relationship with a Texas Instruments or a Duracell, they know what to do with any product that results. But what about the Glutz R&D Co. that with federal support has developed a hot water heater that really works? We have to have the wisdom of venture capital involved at an early stage to see whether this is the kind of product they might want to get involved in," Blase continues. "I don't know how to do that, but I certainly intend to find out."

### Cooperative Agreements

There is more to attracting venture partners than simply protecting proprietary interests, however. Traditionally, government procurements have been geared more toward tangible items, such as heating oil or ballpoint pens, where there is a clear buyer-seller relationship. As a result, the regulations governing federal procurement call for an extremely one-sided relationship.

There are, for example, 23 clauses that are required by law to be included unchanged in federal contracts. These clauses include equal opportunity, officials not to benefit, Buy America, examination of records by the comptroller general, and similar provisions. Along with these provisions come many heavy reporting requirements. The end result has been that many of the most capable research organizations refuse to do federal contract research on the simple grounds that it is too much bother.

One recent development that has helped DOE to enter into ventures with industry has been the advent of the cooperative agreement. Aided by language in the federal Nonnuclear R&D Act authorizing ERDA to enter into undefined cooperative agreements, ERDA negotiated pioneering agreements in 1977 with Sundstrand Corp. for the development of the bottoming cycles for heat engines mentioned earlier and then with Carter Oil Co. (an Exxon affiliate) for the pilot demonstration of the Exxon Donor Solvent coal liquefaction process. (EPRI is also a major participant in this $340 million project.) Half of the cost is now being shared by DOE, which retains a proportionate share in licensing revenues from the project.

Renegotiating the agreement of several hundred pages was an awesome task, but it allowed Exxon and its industrial partners to avoid standard contract clauses. It also gave them the flexibility they needed to mesh their way of doing business with the government's. DOE is now negotiating cooperative agreements in a number of its R&D programs.

The passage of the Federal Grant and Cooperative Agreement Act of 1977, however, took much of the bloom off the cooperative agreement from an industry point of view, according to Leonard Rawicz, assistant DOE general counsel for procurement and financial incentives. "The principal reason for entering into the agreements is to gain flexibility," he explains, "but the 1977 act made all rules dealing with federal grants applicable to cooperative agreements. The rules aren't as burdensome as those dealing with contracts, but they're still there," he says.

So the search for better mechanisms for joint government-industry ventures continues. The framework may already exist, Rawicz points out. The Energy Security Act signed into law last June specifically authorizes the Synthetic Fuels Corp. to enter into joint ventures for the demonstration of synthetic fuel modules. The act says SFC can contribute no more than 60% of the cost of the modules, which are analogous to a single process train of a commercial synthetic fuels plant.

Synfuels developers concerned about the heavy hand of government may draw some solace from the SFC role spelled out in the law: "The corporation's participation in any joint venture . . . shall be limited to financial participation only and shall not include any direct role in the construction or operation of the module." ■

# NDE Center Dedicated

The doors were opened on a central facility that will evaluate new techniques of nondestructive inspection and speed their transfer into the field.

Floyd Culler and U.S. Senator Jesse Helms were the featured speakers during last month's dedication ceremonies for EPRI's Nondestructive Evaluation Center in Charlotte, North Carolina.

Culler commented, "This unique facility will speed the transfer of research results into hardware that can be applied in the field by the nation's utilities. It will also identify equipment failures quickly and precisely should they occur."

Helms described the new research facility as a remarkable resource for the state and said its operation "will reinforce the remarkable safety record of the nuclear power industry and the positive potential of nuclear power." He added that the center's sponsors will be recognized as pioneers in the field of R&D who have left a legacy for future generations.

The main focus of the NDE Center is to evaluate and qualify new inspection methods designed to help maintain the reliability of components used in nuclear power plants. An interesting story about the NDE Center's techniques and apparatus appeared in the July-August 1980 issue of the *Journal*, pp. 16–20.

The center will offer training courses on new hardware and procedures. It also includes the BWR Owners Group, Pipe Remedy and Training Facility, which will develop new repair technologies and methods of failure prevention for nuclear piping components. J. A. Jones Applied Research Co., a subsidiary of J. A. Jones Construction Co. of Charlotte, will operate the center for EPRI. ■

## Division Director Appointed

John J. Taylor, for 31 years in nuclear power research at Westinghouse Electric Corp. and recently vice president and general manager of the Water Reactor Division of Westinghouse Power Systems Co., has joined EPRI as director of the Nuclear Power Division. He succeeds Milton Levenson, who resigned from that post—held since EPRI's establishment—to join Bechtel Corp.

Taylor's first assignment with Westinghouse in 1950 was at Bettis Atomic Power Laboratory in Pittsburgh. He advanced from senior scientist through various management positions involved with the development of the first nuclear propulsion systems for U.S. Navy submarine and surface ships. He also worked on the first commercial-scale demonstration U.S. nuclear power plant, which was built by the Atomic Energy Commission and the Bettis organization at Shippingport, Pennsylvania. He became engineering manager of the Westinghouse Commercial Nuclear Power Group in 1967 and in 1970 was appointed general manager of the Breeder Reactor Division. He was elected a corporate vice president in 1974 and named to his most recent position at Westinghouse in 1976.

Taylor earned a BS from St. John's University in New York City and a master's from Notre Dame University—both in mathematics. He served in the Navy during World War II, then worked as a mathematician at Bendix and Kellex corporations prior to joining Westinghouse.

The National Academy of Engineering is one of many professional societies of which Taylor is a member. He has been adviser to the National Bureau of Standards, the General Accounting Office, the Office of Technology Assessment, and Oak Ridge National Laboratory and has served on a variety of professional and industrial committees. Taylor is coauthor of the *Reactor Shielding Manual* and co-editor of the *Naval Reactor Physics Manual*, as well as the author of many professional papers. ■

## First Shale Oil Burn Successful

Oil from shale appears to be an acceptable fuel for electricity-producing turbine generators, according to tests conducted for EPRI by United Technologies Corp. and Long Island Lighting Co.

"Although all the test data have not yet been fully processed," commented Henry Schreiber, EPRI project manager, "it appears the shale oil residual fuel is a potential for combustion turbines."

Schreiber noted that the 23 hours of testing, which was conducted in separate burns of 4–5 hours each, focused on monitoring engine performance, emissions, and the effect of the shale oil on the engine and system hardware. Engine operating temperatures were not excessive, and the internal engine hardware exposed to the flame and combustion products appeared clean.

The early results indicate the gases produced by burning shale oil residual are similar to those from conventional fuel oils, although somewhat higher in nitrogen oxides ($NO_x$). The tests also indicated that the $NO_x$ emissions could be reduced by mixing water with the shale oil residual going into the engine, which is standard practice by utilities to reduce $NO_x$ emissions from conventional fuels. ■

## CALENDAR

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

### APRIL

**8**
**Nuclear Fuel Performance—Contractors' Overview Meeting**
Boulder, Colorado
Contact: David Franklin (415) 855-2408

**8–10**
**Workshop: Rate Design Study—Costs and Rates**
Atlanta, Georgia
Contact: Nancy Hassig (415) 855-2176

**14**
**Seminar: Synfuels for Utility Application**
Washington, D.C.
Contact: Tasia Toombs (415) 855-2510

**15**
**Seminar: Synfuels for Utility Application**
Chicago, Illinois
Contact: Tasia Toombs (415) 855-2510

**22–24**
**Workshop: Rate Design Study—Costs and Rates**
Kansas City, Missouri
Contact: Nancy Hassig (415) 855-2176

### MAY

**13–14**
**Workshop: Coal Liquefaction Contractors**
Palo Alto, California
Contact: Cheryl Landers (415) 855-2511

### JUNE

**2**
**Seminar: Synfuels for Utility Application**
Los Angeles, California
Contact: Tasia Toombs (415) 855-2510

**2–4**
**Technology Seminar I: Communications Systems for Distribution Automation and Load Management**
Atlanta, Georgia
Contact: A. Johnson (415) 855-2833

**3**
**Seminar: Synfuels for Utility Application**
Houston, Texas
Contact: Tasia Toombs (415) 855-2510

**16–18**
**Technology Seminar II: Communications Systems for Distribution Automation and Load Management**
Denver, Colorado
Contact: A. Johnson (415) 855-2833

**23–25**
**Workshop: Modeling for Stability Calculations**
(Attendance limited.)
St. Louis, Missouri
Contact: A. Johnson (415) 855-2833

### SEPTEMBER

**9–11**
**Workshop: Modeling of Cooling-Tower Plumes**
Chicago, Illinois
Contact: John Bartz (415) 855-2851

**17–18**
**Symposium: Underground Cable Thermal Backfill**
Toronto, Ontario
Contact: T. Rodenbaugh (415) 855-2306
S. Boggs (416) 231-4111

**21–25**
**Workshop: Zero Discharge**
Steamboat Springs, Colorado
Contact: Roger Jorden (415) 855-2463
Ronald Kosage (415) 855-2869

### OCTOBER

**26–28**
**Workshop: Modeling the Performance of Cooling Towers**
Chicago, Illinois
Contact: Hugh Reilly (415) 855-2469

## Relief Valve Tests Completed

Testing PWR relief valves at Wyle Laboratories, Norco, California.

EPRI has completed the first series of PWR power-operated relief valve tests at the Marshall station of Duke Power Co. near Charlotte, North Carolina. A special relief-valve test loop was constructed at the power plant early in 1980 for the testing of 10 relief valves and several block valves under full-flow and high-pressure (~2350 psi; 16.2 MPa) steam conditions. These tests were designed to examine the relief valves' operability (their ability to open and close on demand) for anticipated overpressure conditions in PWRs. The results from these full-scale tests demonstrated the ability of the valves to perform under normal design-basis conditions.

The Marshall relief valve tests are part of an EPRI effort to evaluate the performance of PWR primary-system power-operated relief and safety valves used in the reactor overpressure-protection system. This project started in January 1980 with funding by special contributions from 41 U.S. utilities that have PWRs in operation or under construction and is designed to be responsive to NRC's NUREG 0578, section 2.1.2. The valve test data and supporting analyses generated in this project are expected to be used by PWR licensees in their plant-specific responses to NUREG 0737, section II.D.1.

A second series of relief valve tests is in progress at Wyle Laboratories in Norco, California. These tests are designed to evaluate relief valve operability for subcooled water conditions.

The major portion of the PWR valve test project will be performed at a new PWR safety and relief valve test facility under construction for EPRI by Combustion Engineering, Inc., at Windsor, Connecticut. This first-of-a-kind test facility will be able to provide all the valve test conditions required to assess the performance of safety and relief valves under expected operating conditions.

Groups in other countries have also decided to participate in EPRI's PWR safety and relief valve tests: the Almaraz, Asco, and Lemoniz nuclear power stations (each of which has twin PWRs) in Spain; Furnas Central Electricas, S.A., which is building the three-unit Angra station in Brazil; and Framatome, a nuclear steam supply vendor in France.

Several U.S. PWR nuclear steam supply system vendors have indicated they will cofund the tests, and negotiations are in progress with other overseas utilities and organizations who have expressed interest in participating. ■

# R&D Status Report
# ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

## COOL WATER COAL GASIFICATION PROJECT

*Since its inception, EPRI's Clean Gaseous Fuels Program has sought to identify and support the development of coal gasification technologies that show promise for environmentally clean, economical, and efficient power generating systems. A major goal in this plan has been to advance the most attractive of the desirable and suitably developed gasification options to demonstration scale (i.e., application in a power plant of about 100 MW) in an early timeframe, preferably by 1985. EPRI's participation in the Cool Water coal gasification–combined-cycle (GCC) demonstration effort represents the final step in achieving this goal.*

Initial evaluations of various gasification processes by the Clean Gaseous Fuels Program identified the single-stage entrained process of Texaco, Inc., as a strong candidate for near-term utility application. This conclusion was based on the technology's firm foundation in Texaco's commercially successful oil gasification process, its advanced state of development (including several years of pilot plant experience), and its numerous intrinsic advantages: simplicity, feedstock flexibility, fast response, pressurized operation (making it compatible with combustion turbine generators), and high-temperature conditions (which suppress the production of tars and other environmentally troublesome by-products). EPRI-funded tests in pilot plant gasifiers using the Texaco process have confirmed these advantages (RP985, RP1799).

In addition to this process test work, EPRI sponsored engineering and economic studies that evaluated various gasification technologies in many alternative power plant configurations (RP239; RP986-2, -3, -6). Results from these efforts indicated that Texaco-based integrated GCC systems using currently available combustion turbines are competitive in both cost and efficiency with direct-coal-fired plants that use wet scrubbers.

On the basis of its studies and evaluations in the 1970s, EPRI concluded that the Texaco technology should be advanced to the demonstration phase of development in order to address remaining uncertainties. Many of these can be resolved only in tests with equipment of near-commercial size. Thus in February 1980, EPRI entered into an agreement by which it will contribute $50 million to the Cool Water demonstration project being conducted by Southern California Edison Co. (SCE) and Texaco. This sum represents the largest financial commitment ever made by EPRI to a single project.

### Project background and objectives

The Cool Water coal gasification project encompasses the design, construction, and operation of a 100-MW integrated GCC plant that uses a 1000-t/d Texaco gasifier. The project was formally initiated by SCE and Texaco in July 1979. In addition to SCE, Texaco, and EPRI, Bechtel Power Corp. and General Electric Co. have signed agreements committing funds to the effort.

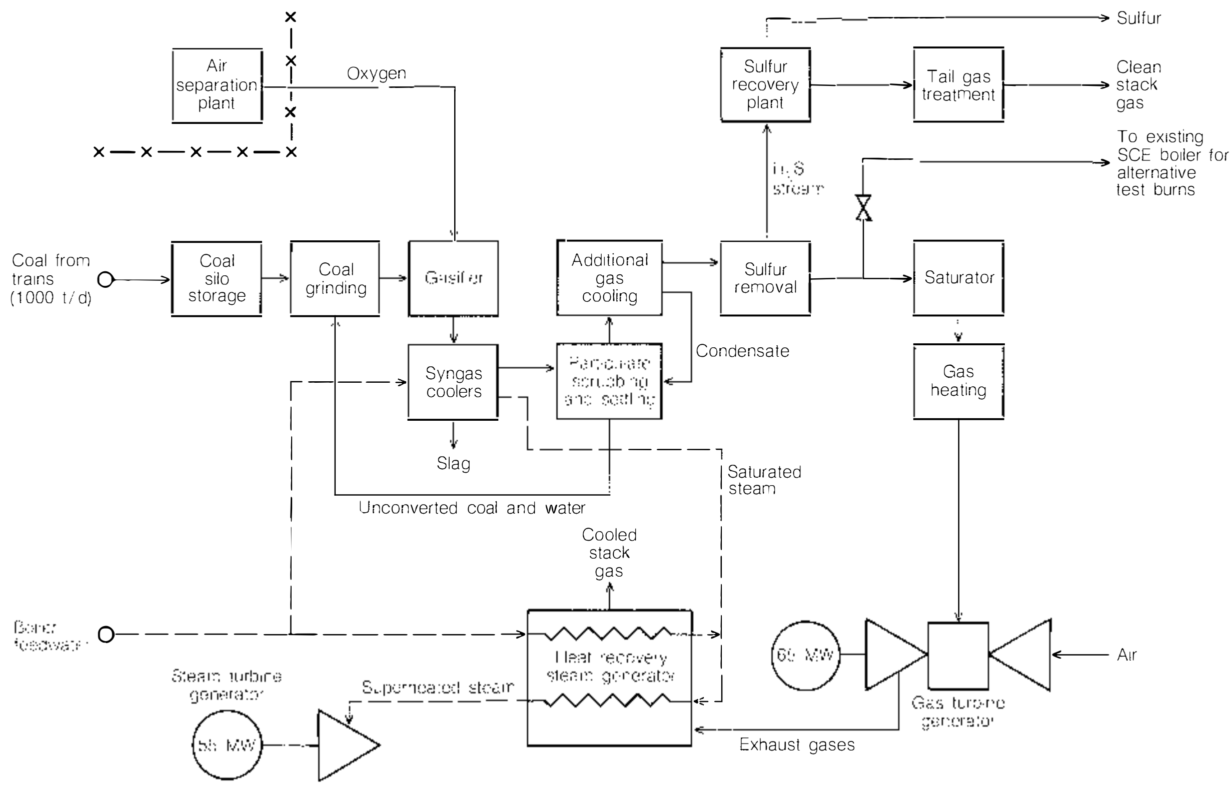
The facility will be located at SCE's 600-MW Cool Water station near Daggett, California (about 120 miles northeast of Los Angeles). It will consist of a coal receiving and slurry preparation section, a gasifier designed for operation at 600 psi (4.14 MPa), syngas coolers (waste heat boilers), particulate and sulfur removal systems, a sulfur recovery unit, combined-cycle power generation equipment (a combustion turbine electric generator, a heat recovery steam generator, and a steam turbine electric generator), and support and ancillary equipment. Among the major objectives of the project are the following.

- To evaluate equipment and system performance at a commercial scale
- To assess overall system controllability under utility operating conditions
- To demonstrate feedstock flexibility by using a variety of coals
- To establish effective operating, maintenance, safety, and training procedures for use in future plants
- To develop a complete technical and economic data base to facilitate design of large commercial baseload plants

### Plant design and expected performance

Figure 1 is a flow diagram for the Cool Water GCC plant. Coal will be delivered from the Southern Utah Fuel Co. mine by unit train to the Cool Water site, where it will be unloaded into storage silos. After the coal has been ground and mixed with water to form a concentrated slurry, it will be fed into the refractory-lined gasifier through a special burner in which partial combustion will take place. Oxygen for the combustion and gasification reactions will be supplied by an "over-the-fence" air separation plant. Although this air separation facility will be a separate, independently owned and operated installation, considerable integration of the unit's instrumentation system with that of the GCC plant is planned. In the gasifier, high-temperature reactions (2200–2800°F; 1204–1538°C) will produce a synthesis gas composed primarily of CO and $H_2$ and having a heating value of about 280 Btu/ft³ (10.4 MJ/m³). The ash in the coal will be melted into a slag, which, after being

**Figure 1** **The Cool Water coal gasification project will couple a Texaco coal gasifier with a gas turbine and a steam turbine in combined cycle to generate 120 MW of (gross) power.**




quenched with water, will be removed as an essentially inert solid through a lock hopper system.

The temperature of the hot syngas will be reduced considerably in both radiant and convection coolers (waste heat boilers), which will produce a substantial quantity of saturated steam. The gas will then be water-scrubbed to remove over 99.9% of any remaining particulates. After this it will be cooled further and processed in a conventional acid gas-removal system to reduce the $H_2S$ and COS content by more than 97%. $H_2S$ and COS stripped from the gas will be routed to a unit for sulfur recovery; the tail gas from this unit will be further treated to minimize sulfur emissions. The clean syngas will be passed through a water resaturator to reduce the flame temperature in the combustion turbine and thus limit $NO_X$ production. Steam will also be injected just before the gas enters the combustion turbine to further minimize $NO_X$ formation.

The intermediate-Btu gas will be burned in a combustor now under development by General Electric and expanded in a gas turbine to drive an electric generator. The hot exhaust gases will be passed through a heat recovery steam generator, where they will produce superheated steam from boiler feedwater and will also superheat the steam generated in the gasifier's syngas coolers. This superheated steam will be supplied to a steam turbine, which will drive an electric generator. After the in-plant power requirements and those of the oxygen plant have been taken into account, the net output of the combined-cycle unit is expected to be about 100 MW. Gas produced in the facility can also be diverted to an existing 65-MW SCE boiler at the site for test burns.

The heat rate of the Cool Water GCC system is expected to be about 10,500 Btu/kWh, which corresponds to a coal-to-busbar efficiency of approximately 32.5%. EPRI studies have shown that in a commercial plant using larger, more efficient steam turbines with reheat, a significant improvement in this heat rate can be expected. The Cool Water plant will not have a reheat steam turbine because this equipment is already in use commercially and its effect on system performance can be extrapolated with reasonable confidence.

Emissions from the plant are estimated to be as follows for the design coal: $SO_2$, 0.04 lb/$10^6$ Btu; $NO_X$, 0.14 lb/$10^6$ Btu; and particulates, 0.005 lb/$10^6$ Btu. Aqueous effluent from the plant will be routed to a lined evaporation pond. Present plans call for on-site storage of the slag removed from the gasifier.

In addition to the design Utah coal, several other coals (both eastern and western) will be tested at the facility. EPRI has designated a high-sulfur Illinois No. 6 coal for testing. Data on this coal have previously been obtained in test runs at the 15-t/d Texaco gasifier at Montebello, California, and at a 165-t/d Texaco gasification unit operated by Ruhrchemie at Oberhausen, West Germany (RP985, RP1799). Results of the Montebello tests were presented in the October 1980 issue of the *EPRI Journal* (p. 37), and the Oberhausen runs will be described in the June 1981 issue.

**Project status and schedule**

After a 16-month environmental review, the California Energy Commission granted the sponsors a construction and operating permit in December 1979. Phase 1 of the project, the conceptual design of the demonstration plant, was completed by the end of 1979, and in February 1980, Bechtel began Phase 2, the detailed engineering design effort. About 20% of this work has now been completed.

A preferred equipment arrangement has been determined through plant configuration studies, and the following key decisions on components and contractors have been made.

- General Electric has been awarded the supply contract for the combined-cycle equipment and has begun engineering work, which includes design of the overall integrated control system.
- Allied Chemical Corp.'s Selexol process has been chosen for sulfur removal, and design work has been initiated.
- Amoco Oil Co.'s Claus process has been selected for sulfur recovery and Shell Oil Co.'s Scot process for tail gas treating. Ford, Bacon & Davis will develop the engineering design for these facilities.
- The major points of agreement for the supply of oxygen have been worked out with Airco, Inc. so the company can proceed with the engineering design of its facilities.
- Combustion Engineering, Inc., has been chosen to supply the gasifier and the syngas cooler vessels and has begun engineering work.

Several other milestones have been reached in the Phase 2 work to date. Pilot plant testing with the design coal has been successfully conducted at the 15- and 165-t/d Montebello and Oberhausen units, the gasification section process design has been completed, a revised preliminary project cost estimate has been prepared, and a preliminary process and equipment test plan has been drawn up. Important steps have also been taken toward fulfilling regulatory requirements. A preliminary detailed environmental monitoring and surveillance plan and a worker safety and health plan have been submitted to the California Energy Commission; application for a prevention of significant deterioration (PSD) permit has been filed with EPA.

Progress has been made in the area of funding. A proposal was submitted to DOE, and in December 1980 the agency announced its intent to award a $25 million cooperative agreement grant to the project. Promising discussions are also under way with two other potential participants. In a related development, the California Public Utilities Commission has approved a financial arrangement enabling project participants to recover all or part of their investment (depending on the capacity factor achieved by the demonstration plant) through a fuel-processing fee to be paid by SCE. This fee will cover operating and maintenance costs and will have a capital recovery component.

Phase 3 of the project will entail procurement and construction. Procurement of the actual hardware is expected to begin this spring, and the current schedule calls for construction to begin in July, when engineering work will be about 40% finished. Construction completion is planned for October 1983. Phase 4, operation and testing of the integrated GCC plant, is expected to start in early 1984 and continue for about seven years. Phase 5, completion, dismantling, and disposal, is scheduled for 1990.

The present cost estimate for design, construction, and startup of the facility is $275 million. Contractual funding commitments to date, including EPRI's, total $150 million. Given the announced DOE award and assuming the successful conclusion of current discussions with one or two other organizations presently considering participation, some $50–$75 million in funding is still needed. A plan to close this funding gap is being reviewed by all participants so that Phase 3 of this project (of major importance to the utility industry) can proceed on schedule. *Project Manager: T. P. O'Shea*

# R&D Status Report
# COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

## BOILER RELIABILITY

*Statistical data from the Edison Electric Institute (EEI) indicate that boilers (not including auxiliary equipment) account for an availability loss in fossil fuel power plants of approximately 15%; thus they are a major contributor to the 35.5% total plant availability loss. EPRI's boiler performance and reliability subprogram was established to develop technology that will reduce boiler outages caused by generic, industrywide problems related to design, operation, and maintenance. A continuing research planning effort is based on EEI equipment availability data, utility industry equipment failure surveys, and input from utility working groups, the EPRI advisory structure, and equipment manufacturers. The result is an R&D effort in which funds are allocated to problem areas in proportion to their contribution to overall boiler availability loss. This work is expected to produce significant short- and mid-term benefits to the utility industry.*

The major problem areas affecting boiler availability—and thus the areas with the highest R&D priority—are boiler tube failures and the slagging and fouling of heat transfer surfaces. Two other important areas of study are the effects of cycling operation and human factors design on boiler availability.

### Boiler tubes

It is well documented that boiler tube failures are the primary cause of boiler unavailability. By a conservative estimate, they account for a 4% loss in the availability of large fossil units nationwide.

Reliability data from national sources summarize boiler tube failures by component and/or location only (i.e., water walls, superheater, reheater, and economizer). These data do not identify or quantify primary failure mechanisms, such as fireside/steamside corrosion, erosion, overheating, fatigue, hydrogen damage, and weld deficiencies. Nor do they indicate the most probable root causes of the failure mechanisms or the corrective and/or preventive action taken. Without more comprehensive data, a cost-effective R&D program that addresses failure mechanisms in proportion to their significance cannot be prudently and expeditiously undertaken.

EPRI is therefore sponsoring projects to develop a more comprehensive understanding of tube failures in fossil fuel boilers. One project, which is nearing completion, has focused on boiler pressure parts (RP1077). Severe water-wall tube failure problems in four utility boilers were investigated, and root-cause determinations were made for the failure mechanisms of corrosion, fatigue, overheating, and acid corrosion–hydrogen damage. A systematic problem-solving approach and R&D recommendations based on the generic aspects of these case studies will be presented in the final report. Another project, just started, is investigating the root causes of failures in dissimilar-metal welds (RP1874). Techniques for predicting weld performance will be developed, as well as guidelines for producing welds with a longer life expectancy.

Corrosion of superheater and reheater tubes, both fireside and steamside, is a serious industry problem. Steamside corrosion, commonly referred to as exfoliation, results in severe hard-particle erosion of major turbine components; fireside corrosion results in boiler tube failures or very costly premature tube replacement. Both kinds of corrosion are being investigated (RP644). A chromate conversion treatment that forms a very hard, oxide-resistant coating has been developed for steamside tube surfaces. This process can be applied in the field, and a full-scale retrofit application will be conducted in 1981 to establish procedures and costs. Work is continuing on the development and evaluation of coatings to inhibit fireside corrosion.

EPRI is planning a project to develop a standardized system for reporting boiler tube failures. This project will provide the utility industry with state-of-the-art information on common boiler tube failure mechanisms, their probable root causes (as determined by commonly recognized failure characteristics), and preferred corrective and/or preventative measures. It will also provide a standard method for recording, analyzing, reporting, and monitoring boiler tube failures. In addition to helping utilities deal with boiler tube problems, this system will help EPRI planners determine R&D priorities and evaluate R&D results.

### Slagging and fouling

Slagging and fouling of the fireside heat transfer surfaces in fossil-fueled boilers have been identified as major causes of boiler outage (FP-422-SR), accounting for an availability loss of approximately 2.7% in large fossil units. To minimize slagging and fouling problems in both existing and new boilers, a comprehensive five-year program has been established to study the complex mechanisms of slag formation and deposition on boiler heat transfer surfaces. Included in the plan are projects to examine coal ash composition and ash behavior in boilers; assess existing methods for predicting slagging and fouling and develop improved methods; identify objectionable ash characteristics; assess ash removal systems; investigate ash-metal adherence and bonding characteristics; and pursue new control technologies for coal and fuel oil ash.

One effort already under way is studying the cyclic thermal shock resulting from the use of water blowers for slag removal; the goal is to relate such shock to the long-term thermal fatigue failure of boiler tubes (RP1650-1). Analytic models for predicting the life of boiler tubes subjected to water blowing are to be developed and validated by laboratory and field tests. Another project is investigating the feasibility of altering the bonding strength of ash deposits by chemical fuel additives to facilitate cleaning during boiler operation (RP1839-2). A third project is using theoretical, experimental, and operational evidence to develop reliable guidelines for the selection of magnesium- and manganese-containing fuel additives to reduce high-temperature fouling and corrosion in oil-fired boilers (RP1839-1).

A project is scheduled to start this year that will gather information from all knowledgeable sources to establish an up-to-date data base on slagging and fouling. This data base will cover current utility operating experience as well as relevant manufacturer design criteria for boilers and auxiliary equipment. It will provide a firm basis for long-range R&D planning and for the control of slag-related problems in large fossil fuel boilers.

Results from research to explain the mechanisms of slag formation and to identify the objectionable chemical characteristics of coal ash are also used by the Coal Quality Program in directing coal-cleaning project activities.

### Cycling operation

Fossil fuel boilers originally designed for baseload operation are being used more frequently to satisfy fluctuating load requirements (i.e., in two-shift operation and in load-following maneuvers that entail going from 100% load level down to the boiler's lowest stable load level). These changes in operation are a result of many factors, including constantly increasing fuel costs, additional nuclear generating capacity, and national energy conservation efforts.

Cycling of fossil units designed for baseload operation involves thermal stress cycles on major boiler and turbine components that can result in significant distortion, low-cycle fatigue, or high-temperature damage. It is imperative that operating personnel know how to achieve maximum startup and load-following capability economically and without impairing plant reliability by exceeding thermal limits.

The major cycling burden is being assumed by older drum-type boilers, and RP1034 examined metal temperatures and thermal stresses for a 500-MW drum-type boiler-turbine unit during cycling operation. The goal was to establish startup, shutdown, and load-following procedures that are safe, reliable, and economical and that minimize stresses on major boiler and turbine components. The project was completed in February of this year.

A number of once-through boilers have design limitations that prevent them from satisfying system cycling generation requirements. RP1266-13 examined the cycling operation of a 380-MW subcritical, once-through oil-fired boiler originally designed for baseload operation. This project, completed in January 1980, recommended design modifications that will enable this type of boiler to perform reliably in cycling service.

### Human factors design

The Three Mile Island accident has focused attention on the need to apply human factors engineering principles to the design of nuclear power plants. A recent EPRI study on the role of personnel errors in fossil plant equipment reliability (AF-1041) showed that human error also contributes substantially to the unavailability of fossil plants. A significant finding of the study was that the system most prone to human-induced failures was the boiler and its auxiliaries. Thus a comprehensive program has been initiated to develop and ultimately demonstrate improved human factors designs for fossil fuel boiler systems.

The first project in this program, recently completed, assessed the degree to which human factors engineering principles and data are implemented in the design of modern boiler systems used in utility fossil plants (RP1266-20). It was found that the designs of utility boilers rank well below average in this respect. The second major project, expected to start this year, has the objective of developing human factors design criteria specific to the operation and maintenance of fossil fuel boilers (RP1752E). These criteria will be based on a comprehensive analysis of functional and task activities related to the system and will be integrated with established human factors design guidelines. A future project with cosponsoring utilities will develop conceptual designs for improved boiler systems.

### Future research

In addition to the four major areas discussed above, significant R&D will be undertaken in the areas of thermal performance monitoring, diagnostics, and boiler maintenance. Several projects are in the planning stage and will be initiated in the near future.

The goal of the boiler subprogram—to improve the reliability and performance of fossil fuel steam generating equipment—is in keeping with the national goals of efficient energy use and reduced dependence on foreign oil and gas. The R&D investment in this effort is relatively small and the probability of success, with potentially significant economic benefits to the utility industry, is high. *Project Manager: John Dimmer*

## FABRIC FILTER RESEARCH

*EPRI is supporting a major research program to optimize the performance of fabric filters (baghouses) in pulverized-coal-fired utility boiler applications. The cornerstones of this program are testing at the 10-MW fabric filter pilot plant being operated at the Arapahoe station of Public Service Co. of Colorado, and scale-model studies of gas and dust flow. One key finding of these efforts to date is that for successful operation, baghouse units must be designed to achieve uniform gas and dust flow. Another key finding is that in some instances, effective cleaning of the bags is difficult, if not impossible. Both of the problems identified, uneven flow and ineffective cleaning, can lead to significantly higher operating pressure drops than originally anticipated; boiler derating then becomes a possibility. At the present time, the flow problem is much better understood than the cleaning problem.*

### Flow distribution

Test results indicate most baghouses currently in operation suffer from severe maldistribution of flue gas and fly ash, which leads to excessive pressure drop. It appears that pressure drop (measured with a manometer and expressed in inches of water) can be reduced by 2 in $H_2O$ or more by the retrofit of flow distribution splitter vanes in strategic locations. Splitter vanes should also improve the bag-to-bag dust and gas distribution, although it is difficult to quantify this effect and its benefits at this time. For new units, it is possible to specify ductwork designs that avoid the excessive draft losses experienced in existing units. This can be accomplished through well-planned and carefully performed flow-modeling studies. Vendor-supported modeling studies have historically not been sufficiently detailed to achieve this goal.

Uniform, disturbance-free flue gas velocity profiles within the baghouse are crucial in achieving lower pressure drops, longer bag lifetimes, and ultimately, smaller and more reliable units. This is especially true in three critical baghouse locations: the takeoff duct between the inlet manifold and the compartment hopper; the hopper region below the tubesheet; and the outlet duct from the compartment to the outlet manifold.

*Takeoff Duct* Three designs are prevalent in the industry: 90° turn downward into a bottom takeoff through a circular duct, which then makes another 90° turn to the horizontal upon entering the hopper; 90° turn into a horizontal takeoff through a rectangular or circular duct into the hopper; and 90° turn downward into the hopper through a rectangular duct. All these designs can create excessive pressure drop and poor flow distribution, although the specific effects of each can be quite different.

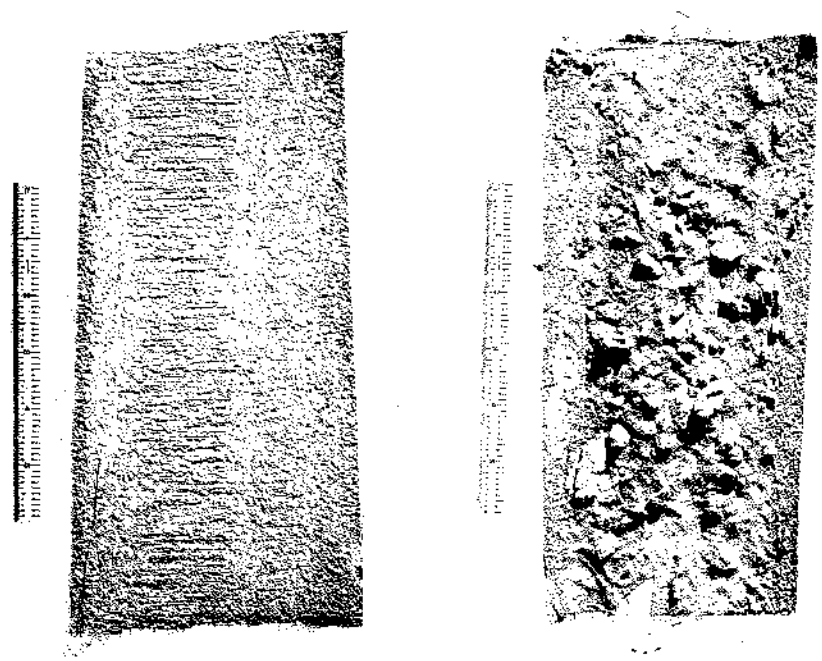
The first, called an elbow design, has two characteristics that lead to excessive pressure drop and poor flow distribution. First, the bottom takeoff promotes flow separation at the elbow entrance, which reduces the effective duct area by almost half. This leads to gas inlet velocities that are higher than the design velocity by a factor of two. These high velocities, over 80 ft/s (24 m/s), virtually ensure poor gas and dust distributions. (It should be noted that even the typical design inlet velocity, 40 ft/s (12 m/s), is sufficiently high to preclude uniform flow profiles within the compartment.) Second, the 90° turn in the elbow causes the incoming gas to swirl. Thus an extremely turbulent, fast-moving (swirling) jet of flue gas enters the baghouse compartment. The result is high pressure drop and severe flow distortion in the hopper.

The side and downward takeoff designs represent a slight improvement over the elbow design in one respect—the swirl effect is eliminated. However, both show a large flow separation at the entrance to the takeoff. Further, the downward takeoff design has potentially the worst hopper flow profile because the gas is jetted into the bottom of the hopper, which promotes turbulence and fly ash reentrainment.

The flow-modeling studies indicate that retrofitting inlet splitter vanes will eliminate flow separation and swirl effects. One result will be a nominal 0.5–1.0-in $H_2O$ reduction in pressure drop, but a more important improvement may be better flow distribution in the hopper. For new installations it is possible to design systems that do not need splitter vanes. Videotapes are available that illustrate the effects described above.

*Hopper Region Below the Tubesheet* Flow events in the hopper are closely related to the inlet gas velocity profile. The high design inlet velocity characteristics of many existing units will lead to severe gas turbulence in the hopper, resulting in fly ash reentrainment and stratification. The flow separation and swirl effects described above exacerbate this situation. Modeling studies are planned to quantify the reduction in pressure drop possible by achieving uniform hopper velocity profiles.

Figure 1 Representative samples of fabric filter bag material after cleaning. Bag cleaning with a shaker-deflate system (left) is much more effective than with reverse gas cleaning (right), which leaves large fly ash nodules on the bag.



*Compartment Outlet Duct* Analyses of compartment outlet designs indicate that this region has been generally ignored by designers, and as a result, significantly lower pressure drops are possible by appropriate ductwork design. In the case of existing units, pressure drop can be reduced by approximately 1 in $H_2O$ by retrofitting splitter vanes near the outlet valves.

**Bag cleaning**

A significant problem identified in testing at the Arapahoe pilot plant involves the formation of a difficult-to-remove nodular cake of fly ash on the bags. Pressure drops in excess of 10 in $H_2O$ across the fabric have been measured. A characteristic of the problem is the high residual pressure drop achieved after cleaning; for example, the pressure drop may decrease only to 8 in $H_2O$ (from 10 in) after cleaning and then rise again quickly. A similar problem has been observed in several fullscale baghouse installations.

Examination of the dirty side of the bags reveals large clumps of material sticking to the cloth—up to 50 lb (23 kg) of fly ash per bag. Microscopic examination seems to indicate that nodules of fly ash encapsulate loose fibers of the fabric, possibly fibers attached to the textured yarn used in the fill direction of the cloth. Initially it was suspected that this material was the result of acid dewpoint excursions occurring during startup and shutdown of the baghouse. However, a more recent theory suggests that fine particles may be partially responsible—that because of their extremely high adhesive qualities, the fines agglomerate and form difficult-to-remove fly ash nodules. Laboratory observations at Carnegie-Mellon University support this novel theory. Tests are under way at Arapahoe to develop more data on nodule formation.

Regardless of how the nodular cake forms, the results are ineffective bag cleaning and high pressure drop. Although efforts at Arapahoe to solve the problem are in an early stage, it does appear that a shaker system with a deflate capability is much more effective than reverse gas cleaning (Figure 1). Also, the effectiveness of reverse gas cleaning appears to be related to the amount of fly ash that has collected on the bag; that is, the more the dust cake is allowed to build (higher pressure drop), the more effectively the bags are cleaned (lower residual pressure drop after cleaning). It must be stressed that these results are preliminary. Further testing is being conducted to verify and quantify the findings. *Project Manager: Robert Carr*

# R&D Status Report
# ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

## OVERHEAD TRANSMISSION

### Bulk-graded, filled polymeric insulators

Polymeric insulators that are electrically graded would offer a number of potential advantages to both utilities and customers—for example, improved performance, greater reliability, and reduced maintenance cost. Such grading would lead to a redistribution of the electric field by eliminating the normal nonuniform voltage distribution inherent in all conventional insulators. A more uniform distribution would significantly reduce the occurrence of flashovers and the costly outages they can cause.

General Electric Co. has been investigating the possibility of using a dielectrically graded filler system (with an epoxy binder and other conventional inert fillers in the overall formulation) to selectively grade polymer insulators (RP1496). This approach was elected in an early phase of the project (*EPRI Journal*, November 1979, p. 51), during which three types of fillers were evaluated: linear-resistive fillers, nonlinear-resistive fillers, and capacitive fillers. Some of the linear-resistive and nonlinear-resistive systems showed promise, but the capacitive approach was chosen because it promised greater potential for success within the predetermined timeframe of the project. (In the early portion of the study, General Electric also evaluated the use of various resin binders and inactive silica fillers of various sizes.)

A mechanical model was developed based on the packing characteristics of spheres of two sizes. Electrical models were developed for both types of resistive-graded fillers, and capacitive grading was modeled by considering voltage distribution in a system, which is an inverse function of capacitance. The design of the laboratory models was guided by analysis of the flux plots generated by a computer.

The best electrical test results were obtained on model insulators having a relatively high dielectric constant for just over half their total length and a relatively low dielectric constant for the remaining portion. Mechanical test strength results on these systems were typical of those for conventional cast formulations.

With the project now approaching completion, General Electric has demonstrated that it is possible to achieve about a 15% increase in critical flashover voltage on small laboratory samples in a polluted environment. Testing is currently in progress on somewhat larger samples. It is particularly significant that when flashover tests were conducted with the insulators upside down (so there would be no grading effect), results were the same as for the ungraded control samples. This demonstrated the effectiveness of the grading phenomenon in reducing flashover.

The objective of this project—to determine feasibility of the concept—has been achieved; the objective of any further work would be to define the performance limits more precisely. *Project Manager: Bruce Bernstein*

### Insulator workshop

An important EPRI service is to provide a forum for the exchange of technical information between utilities, researchers, manufacturers, and universities. A good example of an effective, low-cost means of providing this service is the workshop on transmission line insulators held in Los Angeles on December 10 and 11, 1980. This workshop, chaired by T. C. Cheng of the University of Southern California, focused on the insulators that will be needed for the next generation of ac and dc transmission lines.

The results of studies reported at the workshop indicate that for higher-voltage ac lines, creation of optimal insulation systems will not be accomplished by merely adding more suspension insulators to the string. For HVDC, it was suggested that insulators borrowed from ac technology may be surpassed by new designs made practical by new insulating materials.

The following are a few examples of the topics covered at the workshop.

- Results from both laboratory and field studies on contamination of dc insulators
- Results of tests on contaminated insulators at Project UHV for dc voltages above 600 kV
- A proposed artificial testing method for dc insulators, whose results closely agree with those of field contamination tests
- Insulator designs for UHV lines
- Conceptional and prototype designs based on nonceramic materials, including the use of resistive and capacitive grading
- Insulator operating experience on the HVDC Pacific Intertie line
- The performance of nonceramic materials under dc voltage

The timing of the insulator workshop coincided with the completion of three EPRI projects on HVDC insulation: one on contamination effects resulting from HVDC insulator flashover (RP848) and two on HVDC insulator development (RP1206-1, -2). Final reports on these projects will be available in mid-1981. The papers presented at the workshop will be published in the June 1981 issue of *IEEE Transactions on Electrical Insulation*. *Project Manager: John Dunlap*

## TRANSMISSION SUBSTATIONS

### Acoustic detection of partial discharges

Field detection and location of partial discharges in operating transformers is the objective of a project with McGraw-Edison Co. (RP426). Two types of instruments are being developed for this purpose. One is a relatively inexpensive detector for sensing the presence of a partial discharge on operating transformers; the other is a more expensive detector for both sensing and locating a partial discharge.

The first detector has been finished, and 10 prototypes have been made. These will be evaluated by several host utilities and will also be used on several EPRI projects. For example, the prototypes can be used on capacitors for detection of incipient tank rupture, for dielectric tests of two-phase-cooled transformers, and for detection of partial discharges during the evaluation of Polysil* insulation at the Bonneville Power Authority. McGraw-Edison is using the detector to test new transformer designs in its plant at Canonsburg, Pennsylvania, and EPRI is using it to test for separation of charges in the Freon cooling system of the gas-insulated valves for the dc compact link at Consolidated Edison Co. of New York, Inc. Several host utilities have recorded combustible gas readings in their transformers and will check for possible partial discharges.

Although these initial detectors will not be able to locate the partial discharge, they can be used to determine whether the magnitude of the discharge changes with time. Utilities are encouraged to seek other applications for the device, such as detection of partial discharges in bushings, high-voltage current transformers, capacitors, and converter transformers.

In 1981 a second group of instruments with two transducers will be available; these will be capable of both sensing and locating partial discharges. The two-channel instrument will also be useful in determining the severity and extent of a discharge so that decisions can be made on whether to repair a unit in the field or at the factory; such a determination depends not only on the instrument readings but also on knowledge of the transformer geometry, the amount of gas dissolved in the oil, and acoustic data relating the severity of the discharge with readings obtained from the detector on laboratory samples.

The largest amount of acoustic signal attenuation takes place in the oil and depends on the amount of dissolved gas present; a knowledge of the amount of attenuation is necessary for determining the severity of the discharge. The quantitative data from the project is needed to determine the extent of the damage. The geometry of the transformer must be known precisely in order to determine the severity of the discharge. The best source for information on geometry, of course, is the manufacturer; manufacturers should become familiar with the use of this two-channel instrument so they can properly coordinate with a utility and help it reach the proper decision on repairing a transformer.

Dunegan-Endevco Co. in San Juan Capistrano, California, will market the single-channel device directly to utilities and can be contacted at (714) 831-9131. Additional work will continue through 1981 to perfect the two-channel device. *Project Manager: Edward Norton*

### PCB detector

In the past, utilities have had no simple, reliable, routine method for testing transformer oil for PCB content. In response to this need, General Electric has demonstrated a field-usable instrument that can determine whether the PCB content of a transformer is close enough to the EPA regulation limit to warrant further laboratory analysis (RP1713).

General Electric investigated several promising techniques based on commercially available instruments. The most promising was an X-ray fluorescence analyzer manufactured by Horiba Instruments, Inc. During the course of the work, General Electric informed Horiba that an instrument with greater sensitivity was needed, and Horiba undertook the task of developing it. This new instrument was successfully demonstrated at EPRI in December 1980.

The improved instrument (model MESA-200) quantitatively measures total chlorine content in transformer oil over a range of 0–100 ppm chlorine, with a standard deviation of ±5 ppm at 10-ppm concentrations. The ability of the analyzer to attain such accurate measurements at extremely low levels is attributed to the use of two techniques: X-ray spectral deconvolution by least-square fitting and automatic interference compensation by multiple regression procedures. Previous X-ray fluorescence methods could not automatically correct total chlorine analysis for varying sulfur concentrations. Because the new method is nondestructive, the detector can repeat the analysis up to 99 times and compute average total chlorine values and standard deviations. The time of measurement can range from 10 to 1000 seconds. Spectral data, quantitative data, time, and test number are printed on a paper tape.

Analysis of thousands of samples at General Electric led to the conclusion that a detector measurement of 30 ppm chlorine assures the utility that less than 50 ppm PCBs are present in the transformer oil. The first instrument has been purchased by EPRI and will be used in a follow-on project with a cooperating utility to determine the most economical application procedure. The analyzer is available commercially from Horiba Instruments, Inc., of Irvine, California. *Project Manager: Edward Norton*

## DISTRIBUTION

### Distribution vacuum arc fault current limiter

McGraw-Edison, under EPRI funding, has just completed the developmental phase of a project to produce a distribution-class fault current limiter that uses vacuum arc technology (RP1140). Although specifications and drawings for such a device have been completed, EPRI is not funding follow-on work to develop a working prototype.

The scope of the EPRI project was to include a demonstration of the feasibility of using the vacuum arc concept as the basis for a distribution-class fault current limiter, development of design specifications, construction of two 15-kV single-phase test models, testing of model performance, and completion of a final report. The device was to limit the first loop of fault current without generating transient voltages detrimental to the power system.

Two applications of the vacuum arc approach were to be investigated. In one concept, the vacuum arc would be used as a commutating switch that would divert the fault current into an auxiliary parallel energy-absorbing component. In the other concept, the vacuum arc itself would perform as the energy-absorbing component in the fault current limiter.

At the start of the project, sufficiently detailed models of the two modes of operation of the vacuum arc were not available; therefore, the first effort was directed toward developing adequate models of these two phenomena. At the heart of this effort was a series of experiments on copper electrodes, where the vacuum arc flashes between a hollow cylindrical anode and a short rod cathode located at the axis of the anode inside a demountable vacuum chamber. Current for the various experiments was derived from either a capacitor bank or a 60-Hz short-circuit generator.

The energy-absorbing version of the device dissipates energy when electrons fall through an electron space-charge region

*Polysil is an EPRI trademark.

(sheath) and impinge on the anode, where most of their kinetic energy is converted to thermal energy (a small portion of this kinetic energy is emitted from the anode as X rays). In this mode of operation, without applied magnetic field, the parameter that determines the device's effectiveness is the heat loading at the anode.

By using the model developed for this mode of operation, it was concluded that nonuniform heat loading of the anode and the resulting threat of anode spot formation made it undesirable to use the device as the energy-absorbing, current-limiting component in a fault current limiter. It was decided that the device was best suited for use as a commutating switch with externally applied axial magnetic field.

In the model for the commutating mode, the magnetic pressure of the field forces the plasma away from the anode, resulting in the conduction of current through the sheath near the anode. Conduction of current through this sheath results in a high arc voltage, which is sufficient to commutate the current into the parallel impedance. In this mode, the parameter that determines the device's effectiveness is the neutral-particle density.

The maximum current for which reliable commutation was observed when using the electrodes in the demountable chamber was 6.4 kA instantaneous. Currents of 8 kA instantaneous were commutated less reliably. The parallel impedance for these tests was a 32-$\mu$F capacitor in parallel with a 1-ohm resistor. Peak transient recovery voltages appearing after these commutations were in the range of 6–8 kV, but this voltage was inherent in the test circuit and does not represent a maximum voltage capability for the device.

The specifications and drawings for a sealed, baked-out 20-kA prototype commutating switch were made by using the scaling laws available from the model of the commutating switch. This device was designed with an anode radius of 15 cm and an anode height of 36 cm. Because distribution fault current limiters are not in demand at this time, the additional funds required to build and test this 20-kA prototype commutating switch were not available, and the project was discontinued before construction of the prototype began. Three other factors were important in the decision to discontinue further work: assurance of fault current limiting during the first half-loop was not achieved; the commutating and energy-absorbing components added unacceptable complexity and size to the unit; and a survey of utilities indicated that the device would cost more than they were willing to pay.

Possible future work toward developing this device as a commutating switch would involve building and testing the 20-kA prototype to confirm the scaling laws used and optimizing the cathode material, the time rate of increase of the magnetic field, and the size of the parallel capacitor. The vacuum arc device could also be considered as an alternative switching device for dc applications. *Project Manager: Robert Tackaberry*

**Destructive failure of distribution transformers**

The typical distribution transformer, using oil for insulation and cooling, is subject to destructive failures when arcing occurs in the oil. Arcing may be initiated by an internal fault in the transformer or by the operation of a primary, oil-immersed fuse. The arc decomposes the oil and hydrogen gas is generated, resulting in a high-pressure shock wave hydraulically transmitted throughout the transformer. This shock wave can blow off the transformer cover or mounting bushings or rupture the transformer tank; sometimes it even causes the ejection of burning oil. This destruction of pole- and pad-mounted transformers can result in personal injury, property damage, or environmental contamination. The conventional means currently used to minimize this problem (which include stronger tanks, pressure relief valves, externally mounted fuses, and current limiting fuses) have been neither technically nor economically satisfactory.

McGraw-Edison has been working under EPRI sponsorship on a new transformer design that precludes the use of transformer oil in any capacity, thus removing the cause for destructive transformer failures (RP1143). The development work is based on the use of selected glasses and other high-temperature inorganic insulating materials in conjunction with an advanced insulation application and construction technology. The design being developed for using these materials includes a 50-kVA, 15-kV high-low-low shell-type transformer. Aluminum foil is used for both the primary and the secondary windings, which affords increased mechanical strength during short-circuit conditions and improves capacitive grading during voltage impulses. Physical and electric tests conducted on selected components of laboratory models have shown this overall approach to be workable.

The core-coil assembly of this transformer is designed to operate with losses equal to or lower than the conventional transformers. However, because of the reduced thermal conductivity of the insulation medium, the coil operates at a higher temperature, relying on radiation as the primary means of heat transfer from the core-coil assembly to the tank. The enclosure will have approximately the same dimensions as an oil-filled unit of comparable size; the same quantity of power is lost in both transformer types, thus keeping the overall temperature of this new enclosure equal to that of conventional transformer enclosures.

Although tests on laboratory models have been successful, continued work is required to further develop insulating materials, refine material application methods and techniques, and develop mounting hardware and bushings. Transformer overcurrent and surge voltage protection must also be provided. This work, being performed under Phase 2 of the project, will also be conducted by McGraw-Edison and is scheduled for completion by 1984. Several full-size prototype transformers will be constructed and units provided to host utilities for in-field evaluation. The successful completion of Phase 2 will be a major step toward the overall goal of eliminating the destructive failure of distribution transformers. *Project Manager: Robert Stanger*

# R&D Status Report
# ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

## FUEL SUPPLY ANALYSIS

*Providing timely information on future fuel supplies and advancing the state of the art of supply analysis are the goals of the newly formed fuel supply analysis subprogram. In the recent reorganization of the Supply Program (*EPRI Journal, *October 1980, p. 48), this subprogram assumed responsibility for much of the program's traditional work. It incorporates the activities of the former subprograms in natural resources, energy production, and supply from new technologies, as well as work on energy transportation. The other new subprograms are electricity supply, utility planning methods, and economic resources. The following report examines what directions the fuel supply analysis subprogram is taking and why.*

### New issues in fuel supply analysis

Two observations help define the context of the fuel supply analysis subprogram. The first is that utilities are not in the same position as in 1974. The extent of the change is remarkable. Throughout the country, utilities are a focal point for many of the conflicts within society. As a result, fuel planning—already a difficult task—must now be conducted in an increasingly complex business environment and under much more regulatory scrutiny. The second observation is that the analysis of energy supply has matured a great deal since the OPEC oil embargo. It is therefore appropriate to reevaluate the goals of research in fuel supply analysis in light of what has been accomplished and what can be accomplished.

The principle guiding much of the work to date in the Supply Program has been to do first things first, that is, to estimate costs before becoming embroiled in the many factors that determine prices. This approach was essential during the mid-1970s, when relevant geologic and engineering data and appropriate methodologies were scarce. Now there is a much deeper understanding of how much and what types of information can be obtained about fuel reserves and resources, and methodologies have proliferated for analyzing and interpreting this information within an economic framework.

Yet rather than providing definitive projection, nearly all credible studies must now deal with the uncertainties surrounding their analyses. Researchers are more aware of what they do not know. These uncertainties are based on many questions that extend beyond the geologic and engineering data making up the traditional inputs to supply analysis—questions about such sociopolitical factors as environmental regulations, government policies, and international events. Also problematic are questions about how perceptions of these factors affect industry decisions to develop new energy supplies. These questions may require the development and application of new methodologies that are sensitive to opinions and judgments and that can provide information on uncertainties in a manner useful to the utility decision maker.

Since its formation the Supply Program has been working to develop improved fuel supply analyses. Much less effort can be devoted to these activities than in the past, however, because of the growing importance of other issues (as reflected in the formation of the electricity supply, utility planning methods, and economic resources subprograms) and because of reductions in EPRI staff specializing in fuel supply. Implicit, then, in the research agenda that follows is an overriding emphasis on project selection, ranking, and coordination.

### Providing energy supply information

The subprogram will pursue its first goal through a combination of in-house analyses, contractor studies, and monitoring activities. While in-house efforts to develop fuel supply forecasts will be reduced, the subprogram will sponsor the development of forecasts by others. Much of this work will involve extending existing studies to reflect assumptions specified by utilities and EPRI.

In the area of resource assessment, the subprogram will monitor what is being learned about resources, including, for example, the results of the National Uranium Resource Evaluation Program; information on deep gas, tight gas, and intractable oil deposits, which may make significant fuel supply contributions at higher prices; and information on the recoverability and quality of coal resources.

The subprogram will also undertake analyses of pertinent topical issues. Examples of possible subjects are the impact of foreign uranium supply and demand on the price and availability of uranium for U.S. utilities; the effects of coal development for synfuels and export on the steam coal market; utility strategies involving the acquisition, maintenance, and divestiture of coal or uranium lands; the implications of concentration and changes in ownership in the coal industry; the scope and impact of Mexican oil and gas reserves; and the impact of government policies on coal transportation.

Finally, the subprogram will review and evaluate work by others. In the area of forecasting especially, there is a need for sound, consistent analyses of various studies, identifying where and why they differ or agree.

### Advancing the analytic state of the art

The rationale behind the second subprogram goal, advancing the state of the art of fuel supply analysis, is that the utility industry and EPRI should not depend solely on government agencies or contracting organizations to conduct the basic research and to foster and test those novel techniques that are of particular interest to the utility sector. Government research may reflect priorities that are different from those of EPRI and utilities. Contracting organizations usually must provide their commercial clients with answers to specific problems that require rapid application of existing methodologies. Yet neither of these groups is insensitive to advances. Often a small effort to improve the state of the art will spread rapidly throughout the analytic community, benefiting all subsequent work. Also, a show of interest in particular work by an organization like EPRI (i.e., one that represents a very large and significant client group) may be sufficient to make government programs more useful to the utilities.

The fuel supply analysis subprogram proposes to continue or initiate such catalytic state-of-the-art studies in several areas. Work will be undertaken to stimulate better definition of resources, for example. Deficiencies in data that pose major uncertainties need to be revealed, and possible improvements in analytic methods to help reduce these uncertainties need to be tested and publicized.

Efforts to improve forecasting methods will also be pursued. Examples include coal supply analysis, research on the coal transportation network, and an effort to model the uranium supply industry.

Engineering-economic models do not represent all the relevant forces that determine energy supplies. For one thing, it is important to better understand what factors affect investment in new productive capacity, particularly in the coal and uranium industries, and to reflect these factors in more realistic forecasts and analyses. The subprogram will sponsor studies toward that end.

The effects of socioeconomic, regulatory, and other nonprice factors on energy supply will be examined. It is no longer realistic to make general assumptions about these intangible considerations for want of data or analytic tools. Instead, they must be treated explicitly. The agenda in this area will require new, imaginative approaches.

The results of subprogram research will continue to be presented in contractor reports and in workshops and seminars. In addition, an annual fuel supply seminar will be conducted. The seminars will present forecasts, special studies, critiques, and various in-house analyses. The annual seminar will also provide a forum for discussing such materials and learning the reactions and concerns of utilities.

### Setting priorities

The fuel supply analysis subprogram is faced with ambitious goals and limited resources. The choice of research projects and topics will be based on many different inputs. In some cases, standing advisory groups of utility experts and experts from other fields will be established. Communication must be two-way. Not only must the subprogram learn the relevant information needs of its various clients but it must also convey to the clients assessments of what information is available and what does not exist.

As the subprogram attempts to address new concerns as well as maintain research on the traditional aspects of energy supply analysis, continued attention will be given to gaining maximum leverage from research projects. Research in areas that also concern other subprograms, such as utility fuel procurement practices and strategies, will be carefully coordinated with efforts by those subprograms. *Project Managers: Thomas Browne, Jeremy Platt, and Edward Altouney*

## EFFECTS OF ACID DEPOSITION ON PLANTS

*The Ecological Studies Program is sponsoring integrated research on the effects of acid deposition on plants. Acid deposition includes both precipitation (acid rain) and the deposition of substances from the atmosphere without precipitation (dry deposition). Plants can be affected by these phenomena both directly (by the direct impingement of acid substances on plant parts) and indirectly (by the alteration of soil chemical conditions). Highly managed agricultural systems are less vulnerable to acid deposition than forest systems, which are strongly dependent on the maintenance of natural fertility and nutrient cycles. In both cases, however, the potential exists for subtle detrimental effects to accrue, gradually decreasing quality, productivity, yield, and marketability and lowering resistance to pests, predators, and competing vegetation. At the same time, some beneficial effects from sulfate deposition have been noted in sulfur-deficient areas, including much of the eastern United States. EPRI has recently initiated six projects to study the effects of acid deposition on crops in the Southeast, Midwest, and Northeast and on forests in the Southeast and Northwest.*

### Forest microcosm research

In October 1978 EPRI cosponsored a symposium in Athens, Georgia, to assess the usefulness of microcosms as research tools. Scientists at that meeting concluded that soil and forest microcosms hold the greatest research promise.

The Tennessee Valley Authority will use microcosms to evaluate the effects of acid precipitation on forest ecosystems in the Southeast in terms of plant productivity and soil fertility (RP1632). TVA has developed a series of forest microcosms that permit plants and soils to be exposed to all natural environmental conditions except rainfall. Instead of natural precipitation, the microcosms will be exposed to four different simulated precipitation treatments for a period of two years. Each treatment will have five replicates. Over the two-year period, measurements will be made of leaf leaching rates and plant nutrient content, leaf physiological and morphological responses, decomposition rates in mineral soil, and leaching rates of mineral nutrients.

To assess the extent to which microcosms accurately simulate a real forest and the extent to which the results of this study can be extrapolated to forest ecosystems outside the Southeast, data from field studies (some of which are described below) will be compared with the TVA microcosm data. The field sites represent a broad range of forest types and regional environmental conditions.

### Nitrogen deposition on forested watersheds

Nitrogen is a necessary biological nutrient that tends to accumulate in forest ecosystems and plays a large role in acid rain. Consequently, it is important to understand the effects of anthropogenic nitrogen—mostly in the form of nitrogen oxides ($NO_x$)—on forest ecosystems. Of specific investigative concern are forest productivity and the effects of forests on the quantity and quality of surface water and groundwater. Utilities have a special interest in $NO_x$ effects because 30% of atmospheric $NO_x$ is attributed to fossil fuel power plants.

TVA will develop a mass balance model for nitrogen in forest ecosystems, which will provide information needed to evaluate and predict the effects of increased $NO_x$ emissions (RP1727). This information will also be useful in formulating benefit-cost ratios for future emission control strategies.

The project will study three experimental watersheds in Tennessee with different proximities to coal-fired power plants and potentially different nitrogen loading rates. A mass balance model will be developed for each watershed by quantifying nitrogen inputs via wet and dry deposition, quantifying nitrogen loss via stream flow, and supplementing these field data with existing data on other aspects of nitrogen cycling. Measurement techniques will include the use of polyethylene deposition plates in the canopy, automatic continuous sampling of particulates on the ground, and standard flow determinations at stream sites.

Mass balance data from the three study sites representing different geologies, hydrologies, soil types, and plant communities will be compared and used as the basis for a comprehensive model. Data from other mass balance studies, especially the integrated lake-watershed acidification study (RP1109), will supplement these results, expanding the model's geographic base and predictive capabilities. This development effort will draw on previous work by TVA and Oak Ridge National Laboratory (ORNL) involving nitrogen pools and transfers.

The data from this project will also be used to evaluate the microcosm data collected by TVA in RP1632.

### Acid deposition–forest canopy interactions

The adverse effects of acid deposition on plants may take the form of visible injury, physiological change, or increased susceptibility to disease and insect infestation. The mechanisms behind these effects cannot yet be explained because of a lack of key information on the chemical characteristics of pollutants at exposure microsites, on the rates and methods of penetration of pollutants to absorption sites, and on the quantity of pollutants absorbed by tissue. ORNL will attempt to develop such information (RP1907).

The work will be conducted at ORNL's Walker Branch watershed and TVA's Camp Branch watershed. These two sites are heavily instrumented, and much information is available on their nutrient cycling. Some tasks will be carried out in environmental chambers at ORNL.

Precipitation samples simultaneously collected above and below the deciduous canopy will be analyzed, and dry particles deposited before precipitation events will be identified and quantified. The solubility of sulfur, nitrogen, and potassium will be measured, along with the strong and weak acids in water leachates of deposited particles and suspended aerosols collected above, within, and below the canopy. Also, the rate of dry deposition on vegetation and the inert collectors will be determined (Figure 1). Sulfate and nitrate concentrations and associated acidity will be measured in sequentially sampled rain events to determine how these parameters vary.

Figure 1 A hydraulic lift is used to collect in-canopy vegetation samples for characterization of dry-deposited particle loading to leaf surfaces.

Foliage and exposed dry deposition plates from the field will be placed in a laboratory tank reactor to measure uptake and transformation of sulfur dioxide ($SO_2$), ozone ($O_3$), and nitrogen dioxide ($NO_2$). Net pollutant uptake by the surfaces will be compared with leachable surface-deposited concentrations determined following the exposure periods. Sulfate data collected in other research programs will be used to evaluate the influence of source proximity and forest type on sulfate deposition.

### Acid precipitation and the nutrition status of forest ecosystems

Forest ecosystems, as mentioned above, are quite susceptible to the chronic effects of acid deposition because of their strong dependence on the maintenance of natural fertility and associated nutrient cycles, pathways, and processes. Another project with ORNL is developing process-level information for use in quantifying the effects of current sulfur emissions levels on nutrient cycles and predicting the consequences of changes in emissions levels (RP1813).

This project has two major objectives. The first is to determine what direct effects the deposition of hydrogen and sulfate ions has on the nutrient status and fertility of the soil in four diverse forest ecosystems—two in Tennessee, which are being studied in other projects described in this report, and two in Washington, which are being studied under other funding. The second objective is to determine the effects of this deposition on decomposer invertebrates in a deciduous forest ecosystem and the ultimate consequences for soil fertility.

Ecological studies of sulfur cycling and other phenomena are under way in all four watersheds. Tension lysimeters have been installed in the watersheds to determine cation-anion balances and hydrogen ion production in soil solutions (Figure 2). Sulfate accumulation (in both organic and inorganic forms) will be measured in soil and vegetation. Sulfur gas flux from soil will also be measured. Experimental plots will be established in the watersheds and treated with different amounts of sulfates. Soil microorganisms will be sampled, sulfur and phosphorus will be measured in litter, and soil pH will be monitored.

**Effects of acid precipitation on agricultural crops**

Two projects have been initiated in this area. Under RP1908 ORNL and Argonne National Laboratory will measure the effects of acid precipitation, in combination with gaseous pollutants, on economically important crops of the midwestern and southeastern United States. Researchers will study the direct effects on crops during a growing season, as well as longer-term effects on soil productivity, and will attempt to determine to what degree these effects are specific to a given crop, soil, and geographic site.

Field studies will be conducted under normal conditions except that artificial rain of selected pH values will be substituted for natural rain. To maximize the results on how acid rain affects crop productivity, normal agricultural procedures will be followed. In additional studies conducted in closed chambers, plants will be exposed to charcoal-filtered air with various levels of $O_3$, $SO_2$, and/or $NO_x$. In all cases, plant growth will be evaluated on the basis of several criteria, including economically significant agronomic yield. Greenhouse studies will parallel the field studies to provide information on the extent to which greenhouse findings can be extrapolated to the field. Emphasis will be placed on the characterization of plant response to stress from acid rain with and without gaseous pollutants and on the analysis of a variety of soil characteristics relevant to agricultural productivity.

A similar project is being conducted by the Boyce Thompson Institute for Plant Research at Cornell University to measure the effects of acid precipitation on economically important crops of the northeastern United States (RP1812). Both laboratory and field experiments will be performed during a three-year period.

Laboratory tests will study the susceptibility of plants at various developmental stages and the effects of acid rain with and without $SO_2$. These tests will be performed on crop plants in pots in a greenhouse or in controlled-environment chambers. The plants will be exposed to simulated rain resembling ambient rainfall. Researchers will attempt to determine the plant growth parameters most susceptible to rain of different sulfate, nitrate, and $SO_2$ contents. They will also study the importance of the frequency and intensity of rainfall, daytime versus nighttime exposure, and the drying time of liquid on leaves.

In the field studies, crops of economic importance in the northeastern United States will be grown in a region where rain has pH values between 3 and 5. Test situations will involve the exclusion of natural rain and the inclusion of one of the following: irrigation, simulated rain similar to ambient rain, or simulated rain with a sulfate concentration at or below the EPA standard. Growth and partitioning of photosynthate will be determined in foliage, fruit, stems, and roots. Plant and crop development rates will be recorded, and yield will be estimated by using dry mass measurements. Crop quality will be determined on the basis of assays of nutritive value and marketability criteria. *Program Manager: Robert Brocksen; Project Manager: John Huckabee*

Figure 2 Installation of a lysimeter plate beneath the litter layer of the mixed deciduous forest at the Walker Branch watershed.

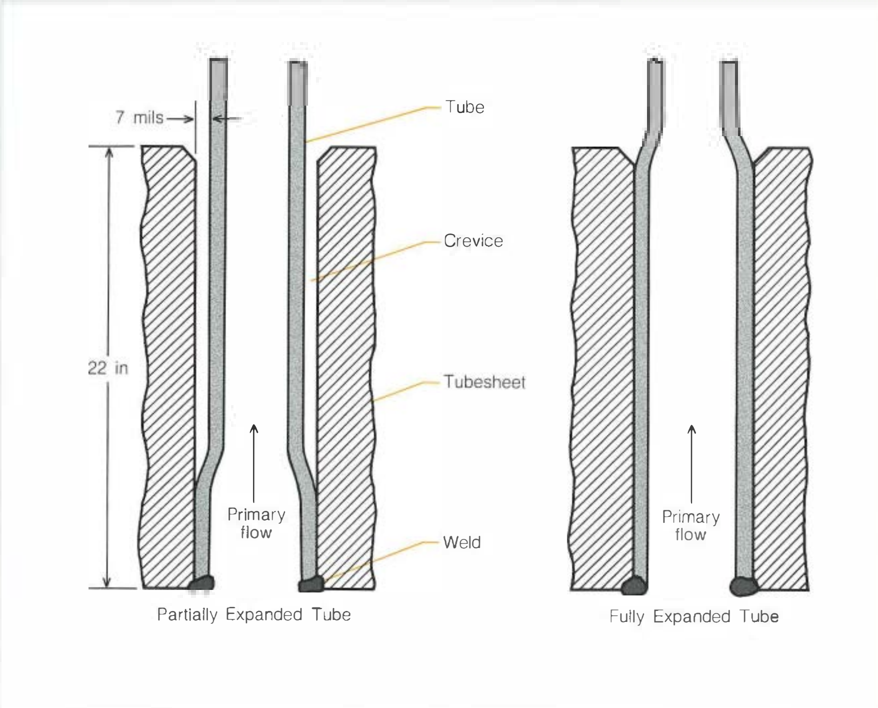
# R&D Status Report
# NUCLEAR POWER DIVISION

John J. Taylor, Director

## STEAM GENERATOR TUBESHEET CREVICE FLUSHING

*Commercial PWR steam generators have been beset with a variety of problems, most of which are associated with corrosion-induced or mechanically induced tube and tube support plate damage. These problems include vibration, fretting and wear, high-cycle fatigue, water hammer, cracking, wastage, pitting, denting, and erosion-corrosion. A utility industry research effort has been funded by the Steam Generator Owners Group and managed by EPRI's Steam Generator Project Office to clarify the causes of the problems and to develop solutions for both existing and new steam generator designs (*EPRI Journal, *April 1978, p. 53). Recently, the Inconel tubes of some recirculating steam generators have experienced a severe form of intergranular corrosion in the tubesheet region. This damage has seriously affected plant availability and has led to tube plugging at one plant and tube sleeving at another. The corrosion has yet to be duplicated in the laboratory to the degree of severity experienced in the field, and the mechanism by which it occurs in the tubesheet crevices has yet to be identified. Efforts are under way by the Steam Generator Project Office to help utilities deal with this problem.*

Figure 1 Tube-tubesheet joint geometries of steam generators used in PWRs.




### Postulated corrosion mechanisms

Tubes in some PWR steam generators are mechanically expanded and welded only at the bottom (i.e., the primary face) of the tubesheet, which is approximately 56 cm (22 in) thick. This results in a deep crevice approximately 0.18 mm (7 mils) wide between the tube and the tubesheet. Some manufacturers have eliminated most of this crevice in newer steam generators by fully expanding the tube (Figure 1). It is postulated that local thermal-hydraulic conditions in these crevices cause chemical impurities present in the bulk steam generator water to concentrate there. Little is known of the flow phenomena that occur in these crevices, but a few generalizations can be attempted.

Bulk steam generator water with a given concentration of a soluble chemical impurity will enter the crevice at the top and begin to penetrate along its length as a result of capillary and gravitational forces. Because of the heat supplied by the tubesheet and the tube, this water starts to vaporize at some point along the length of the crevice. The steam produced escapes through the top of the crevice. At the point of vaporization, the soluble chemical will precipitate out on the tube and/or the tubesheet wall. This dryout position may not remain stationary. It may be extremely unstable; if so, a situation of alternate wetting and drying is created. The deposited salts are alternately moistened and dried, which increases their corrosive effect.

On the other hand, if sufficient liquid is present to redissolve the chemical deposits, this washing action may prevent significant amounts of precipitate from accumulating in any one location along the crevice for a considerable period of time. But as the steam produced must exit through the top of the crevice (i.e., must flow in the opposite direction of the water), a flow regime may develop in the crevice that tends to stabilize the liquid-vapor interface and thus prevent any significant washing action. Aggressive chemicals may then precipitate and concentrate at the liquid-vapor interface, eventually corroding the tube and/or the tubesheet.

Simple calculations show that during normal operation small crevices should be vapor-blanketed over most of their length. Also, tests performed with pure water have shown that for a tube concentric with the tubesheet hole, dryout will occur from 2.5 to 25 mm (0.1–1.0 in) below the top face of the tubesheet, depending on circumferential position (S119-2).

This mechanism alone cannot explain the fact that in one operating plant, tube damage has occurred along virtually the entire length of the crevice. Another mechanism of chemical concentration that has been postulated to operate in conjunction with the previously described phenomena could help explain this damage. The mechanism involves the ability of any solute to raise the boiling point of water. Figure 2 shows the elevations in the boiling point of water caused by various concentrations of sodium hydroxide, which is suspected of being one of the corrosive agents involved in the intergranular attack on tubes in the tubesheet crevices. In plants that continue to use phosphate feedwater treatment, the origin of this caustic may be the hydrolysis of sodium phosphate. In plants that use all-volatile feedwater treatment, sodium hydroxide may be formed by either a complex reaction between sodium phosphate and magnetite in sludge piles developed during previous phosphate water treatment or by concentration and reaction of alkaline-forming cooling water, which may enter the feedwater stream through condenser leaks.

According to this postulated mechanism, the bulk steam generator water migrates down into the crevice until it is heated to its boiling point, as determined by its sodium hydroxide concentration. At this point vaporization takes place, and the caustic begins to concentrate in the remaining water; this raises the boiling point even further and allows further migration of the liquid. Also, as the temperature of the solution is now higher, the heat flux through the tube wall decreases. This reduction in heat flux allows the concentrated chemical solution to penetrate even further into the crevice. Through this process the temperature of the solution can ultimately reach that of the hot primary loop, approximately 324°C (615°F), and the concentration of sodium hydroxide in the solution (as determined from a linear extrapolation of the data shown in Figure 2) can reach a maximum value of about 660,000 ppm, or 66 wt%. (This calculation assumes that the relationship between temperature and concentration does not vary with pressure.) Therefore, it is possible for a highly concentrated solution of sodium hydroxide to penetrate the entire length of the tubesheet crevice.

Another mechanism by which aggressive chemicals may concentrate in tubesheet crevices involves transient operation of the steam generator. As noted earlier, during normal operation the crevice should be entirely vapor-blanketed. But during cooldown of the unit, this vapor bubble can collapse; contaminated liquid can then penetrate the crevice, helped along by the collapsing bubble. When the unit is restarted and heat-up causes the bubble to develop again, aggressive chemicals may concentrate to saturation and precipitate in the crevice or (in the case of sodium hydroxide) concentrate in the remaining solution.

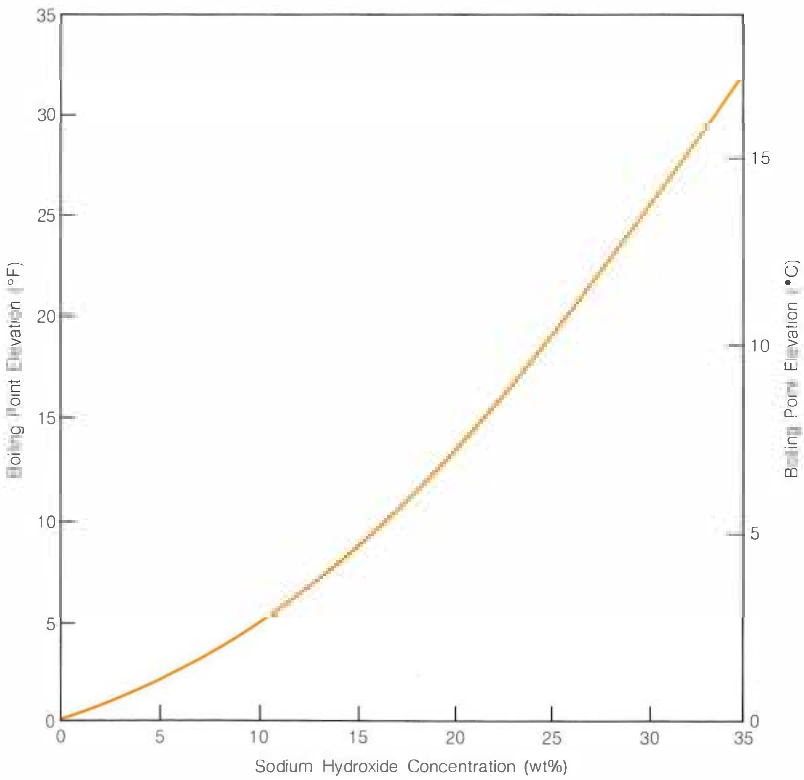



Figure 2 The relationship of sodium hydroxide in water to boiling point elevation. Sodium hydroxide remains soluble over the entire range of temperatures encountered in steam generators. The boiling point elevation is expressed as the increase in temperature above the boiling point of pure water at the same pressure.

### Crevice-flushing techniques

Regardless of how the culprit chemical species get into the tubesheet crevices, the problem is to neutralize or remove them. Because the crevices cannot be cleaned directly, remote procedures are necessary. One process, developed in Japan and then modified and used at two U.S. plants, is crevice flushing. This involves filling the crevices with water and then depressurizing the steam generator to cause bubble nucleation in the crevices, which forces the liquid containing the dissolved chemicals out the crevice top (Figure 3).

To accomplish this flushing, one procedure (which has been applied at Wisconsin Electric Power Co.'s Point Beach station) uses the tubesheet as a large heat storage facility, with the heat being supplied by the reactor coolant pumps. The steam generator is filled with water to a depth of approximately 0.61 m (2 ft), and the system is brought to a temperature of 121 °C (250°F), with the main steam isolation valves on the generator's steam header closed. This causes the tubesheet to reach a uniform temperature of 121°C and the pressure in the generator to reach approximately 0.2 MPa (30 lb/in$^2$), the saturation pressure associated with this temperature. The solution in the crevices is at the same temperature but is subcooled as a result of the head of water in the steam generator. The reactor coolant pumps are stopped, and the unit is allowed to remain in this condition for a short time to permit dissolution of possible chemical deposits in the crevices.

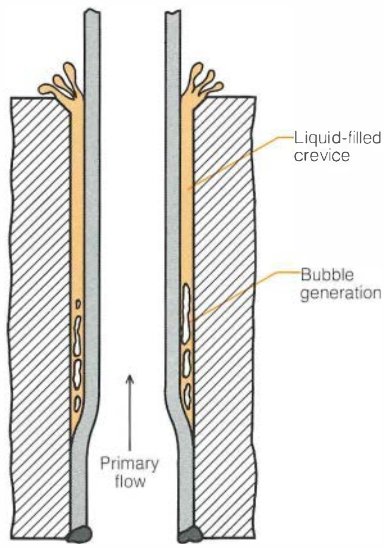
The water on top of the tubesheet is then subcooled by adding cold water. The generator's relief valves are opened and the generator rapidly depressurized. The pressure reduction takes approximately 8–15 minutes. The water in the crevices, which is at approximately 121°C, begins to flash shortly after the start of the depressurization process. The bubbles that are generated force dissolved material and contaminated solution from the crevices into the subcooled water above the tubesheet. This water has not boiled away and is thus able to hold the ejected material. The tubesheet is then cooled to 93°C (200°F), which collapses steam in the crevices. It is anticipated that this in turn will allow the crevices to refill with bulk water containing much lower concentrations of aggressive chemicals. The steam generator is then drained and refilled for another cycle. Each cycle takes approximately 6 hours.

Results from the flushing operations at Point Beach indicate that soluble chemicals in the tubesheet crevices are successfully ejected during depressurization. For example, data from a series of eight depressurization cycles in one steam generator indicate that $10^4$ ppm (1 wt%) of caustic was removed per crevice, assuming all accumulated material came from the crevices.

Variations of the procedure described above have been performed in the field. One involves the creation of nitrogen overpressure in the generator before depressurization to (1) allow the initial temperature of the subcooled water to be increased, (2) increase the rate of depressurization, and (3) allow any steam bubbles formed in the crevices during heat-up to collapse. Another modification involves the application of electric resistance heating to the bottom face of the tubesheet.

The increase in water temperature and the faster depressurization rate that are made possible by nitrogen overpressure result in a more violent boiling action, which was originally believed to enhance the flushing process. The application of electric heating is intended to produce a temperature gradient through the tubesheet thickness, with the higher temperature occurring at the bottom of the crevice. It is believed that with this gradient, boiling will initially occur at the bottom of the crevice, overcoming the liquid head provided by the water in the length of the crevice and above the tubesheet. The water column in the crevice will thus be forced out by bubble generation and growth.

Figure 3 Liquid removal from tubesheet crevices by steam generator depressurization. Bubble nucleation within the tubesheet crevice forces contaminated liquid out the top of the crevice.




These modifications are intended to maximize flushing efficiency, but test results have been contradictory and inconclusive. Laboratory testing in Japan indicated that flushing efficiency tends to decrease as the rate of depressurization is increased. The phenomena involved are not clearly understood, but it is speculated that a slower depressurization rate results in bubble generation that is more gradual, allowing the bubbles to fill the whole crevice and push up the column of liquid.

Testing performed under S183, however, indicates that both a higher initial temperature and a nitrogen overpressure tend to increase the cleaning efficiency of the flushing process. For example, a relatively high removal efficiency—64% of the initial crevice caustic (10 wt%)—was achieved in a series of depressurization cycles with an initial temperature of 171°C (340°F) and a nitrogen overpressure of 0.1 MPa (15 lb/in$^2$). (The crevices were not packed with a foreign solid material like sludge, and the temperature across the tubesheet was uniform.)

The S183 results run counter in some respects not only to the Japanese results but also to the preliminary results of companion tests under S119-2. These tests, performed on a prototype unpacked tubesheet crevice, seem to indicate that a more efficient flushing action results when a uniform temperature is applied across the tubesheet and the depressurization rate is relatively slow. These findings support the practice of using the primary pumps as a source of heat. The S119-2 results also indicate that nitrogen overpressure does not increase the flushing efficiency to any great extent and may, in fact, be detrimental to the flushing process. A further complication is that certain Japanese test results are at variance with the finding that a uniform temperature across the tubesheet is desirable. Obviously, much more work is required before crevice cleaning can be completely understood.

It must be noted that all testing to date has been performed on unpacked (sludge-free) tubesheet crevices. Flushing efficiencies could be affected by the presence of a low-porosity material in the crevice. Such material probably occurs in all plants that have detected sludge in the steam generators. Fortunately, the Point Beach results indicate that sludge packed in the crevices may not have a significant effect. Also, it has yet to be determined how sludge on top of the tubesheet affects flushing efficiency. The Point Beach data indicate that the violent boiling action that takes place during depressurization tends to fluidize and/or break up sludge left in the steam generator after sludge lancing.

The Steam Generator Project Office will continue to sponsor work toward the development of an optimal crevice-cleaning procedure in terms of flushing efficiency and the operational time required for implementation. This work will seek to identify and quantify the effects of various parameters on flushing efficiency. Because the mechanisms of a particular effect may be extremely subtle and may not follow intuition (as has been shown in the case of depressurization rate), further laboratory testing on simulated tubesheet crevices is required. It is intended that by the summer of 1981 the project office will be able to recommend an optimal crevice-flushing technique to utilities belonging to the Steam Generator Owners Group. *Project Manager: David Steininger*

# New Contracts

## Advanced Power Systems

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP1660-1 | Retrofitting and Repowering Oil-Fired Boilers With Gas From Coal | 6 months | 188.6 | Fluor Engineers and Constructors, Inc. *B. Louks* |
| RP1799-8 | Gasification: Analytic Work at Ruhrkohle and Ruhrchemie | 4 months | 132.6 | Texaco, Inc. *N. Holt* |
| RP1802-2 | Analysis of Compressor Wheel Failure | 3 months | 36.9 | Aptech Engineering Services *H. Schreiber* |

## Coal Combustion Systems

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP718-3 | Analysis of AFBC Test Results | 15 months | 52.1 | Combustion Engineering, Inc. *C. Aulisio* |
| RP1260-20 | Research on Methods for Fixation and Disposal of Toxic Liquids/ Sludges | 4 months | 24.8 | Battelle, Pacific Northwest Laboratories *D. Golden* |
| RP1874-1 | Dissimilar Weld Failure Analysis and Development | 4 years | 1999.9 | Metal Properties Council, Inc. *R. Viswanathan* *J. Dimmer* |
| RP1878-1 | Development of a Nonradioactive Tracer for Steam Turbine Thermal Performance Testing | 23 months | 103.8 | General Electric Co. *J. Parkes* |
| RP1884-5 | Feed Pump Hydraulic Performance and Design Improvement, Phase I: Program Design | 6 months | 139.4 | Franklin Research Center *I. Diaz-Tous* |
| RP1886-1 | Effects of Phosphate Environment on Turbine Materials | 11 months | 308.6 | General Electric Co. *K. Lehner* |

## Electrical Systems

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP1942-1 | Application of Microprocessors to Control of HVDC Converters | 14 months | 344.4 | General Electric Co. *J. Reeve* |
| RP7876-12 | Polysil Underground Transmission Line Test | 8 months | 45.0 | Colt Construction *M. Rabinowitz* |

## Energy Analysis and Environment

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP434-44 | Rate Design Study: Integrative Topic Paper | 7 months | 101.7 | Putnam, Hayes & Bartlett, Inc. *R. Malko* |
| RP434-47 | Workshop: Costs and Rates—Planning and Production | 6 months | 23.0 | Haley Corp. *N. Hassig* |
| RP883-3 | Foreign Uranium Supply | 6 months | 24.8 | Nuclear Resources International *J. Platt* |
| RP1009-9 | Support Services for Coal Supply Analysis System Development | 8 months | 20.0 | C.A.C.I., Inc.–Federal *T. Browne* |
| RP1104-4 | Economic Value of Electricity Supply Reliability | 7 months | 13.5 | Boston Edison Co. *A. Halter* |
| RP1370-1 | Measurement of Ammonia, Using Infrared Systems | 18 months | 250.2 | SRI International *G. Hilst* |
| RP1432-2 | Case Studies: Innovation in R&D Planning | 8 months | 43.8 | Booz, Allen & Hamilton, Inc. *S. Sussman* |
| RP1588-2 | Load Data Management and Analysis | 5 months | 40.0 | Stone & Webster Management Consultants, Inc. *E. Beardsworth* |
| RP1814-1 | Energy Analysis and Applications | 18 months | 296.7 | Battelle, Columbus Laboratories *S. Sussman* |
| RP1918-1 | Adapting Residential Energy and Load Forecasting Model to Individual Utility Use | 23 months | 298.6 | Cambridge Systematics, Inc. *S. Braithwait* |

## Energy Management and Utilization

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP1191-9 | Instrumentation of Visitors Center SHAC System | 29 months | 40.1 | Arizona Public Service Co. *M. Lechner* |
| RP1198-12 | Capital Cost of Advanced Batteries for Utility Applications | 1 year | 29.8 | George Consulting International, Inc. *D. Douglas* |
| RP1524-5 | Initial Management Plan for an Electric Vehicle Community | 3 months | 20.0 | SRI International *J. Mader* |

## Nuclear Power

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP1398-6 | Metallurgic Evaluation of Failed Low-Pressure Turbine Disk | 7 months | 31.6 | Southwest Research Institute *M. Kolar* |
| RP1544-1 | TMI-2: Mechanical Component Information and Examination Program | 1 year | 58.1 | Quadrex Corp. *G. Sliter* |
| RP1611-5 | Neutron Detector Testing | 5 months | 50.2 | Department of Energy *P. Bailey* |
| RP1841-1 | Pipe Cracking in PWR Low-Pressure Borated Water Systems | 2 years | 218.6 | Babcock & Wilcox Co. *M. Fox* |
| RP1931-1 | Coolability of Debris Beds | 1 year | 38.0 | University of California at Los Angeles *L. Thompson* |
| RP1938-1 | Evaluation of RELAP: Five Codes for Analysis of LWR Transients | 11 months | 148.0 | Intermountain Technologies, Inc. *J. Kim* |

# 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

**Design Properties of Steels for Coal Conversion Vessels**

AP-1637 Final Report (RP627-1); $4.50

Fracture mechanics were used to evaluate materials properties in simulated aggressive high-temperature, high-pressure environments typical of coal conversion vessel operations. Technique development, crack growth studies, fracture toughness tests, and pressure vessel evaluations are discussed. The data developed were used to make some preliminary design calculations for sample service conditions. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Ramaswamy Viswanathan*

**Feasibility of the Inflow Disk Generator for Open-Cycle MHD Power Generation**

AP-1639 Final Report (TPS79-779); $6.50

This report presents a feasibility study of the inflow disk magnetohydrodynamic (MHD) generator for coal-fired baseload applications. Each design element—combustor, inlet flow path, generator channel, diffuser, and magnet—was evaluated. Flow visualization and pressure distribution studies with a hydraulic model examined the full range of flow regimes through the inlet region and generator duct. Within the uncertainty of the analysis, the performance of the inflow disk generator was found to be similar to that of the diagonal generator. The contractor is Stanford University. *EPRI Project Managers: A. I. Lowenstein and P. S. Zygielbaum*

**Large Wind Turbine Generator Performance Assessment: Technology Status Report No. 2**

AP-1641 Interim Report (RP1348-1); $4.50

To expand the understanding of wind technology and to aid utility system planning, this report presents operation and performance assessment information from large wind turbine generator development efforts and field tests. Recent test results and several design modifications at the four DOE–NASA MOD-0A wind turbines around the country are described, as well as early experience at the MOD-1 field test; planned activities are also outlined. A status update on several privately funded wind energy conversion programs is presented, and the DOE–NASA and privately funded wind turbines are compared. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: F. R. Goodman, Jr.*

**Transmutation of High-Level Wastes by Fusion Reactor Neutrons**

AP-1642 Final Report (RP474); Vol. 1, $2.75; Vol. 2, $4.50

Volume 1 summarizes the results of studies on the use of fusion neutrons for disposing of radioactive wastes. It discusses the types of fusion reactors and the chemical separations required for effective reduction of toxicity by transmutation, and it examines the major cost elements of developing and implementing such a disposal system. Volume 2 summarizes currently available and advanced waste separation techniques for application to transmutation. High-level fission product wastes and the various processing forms are described, and the methods used to define nuclear hazard are reviewed. The contractors are McDonnell Douglas Astronautics Co.–East and the University of Texas. *EPRI Project Manager: N. A. Amherd*

**Development of a Reliability Prediction Methodology for a Gasification–Combined-Cycle Power Plant**

AP-1643 Interim Report (RP1461-1); $7.25

A reliability assessment methodology has been developed to assist in the evaluation, selection, and construction of coal gasification–combined-cycle power plants. This report describes the model and its application to a 1100-MW baseload plant design. Results of the plant assessment and of sensitivity analyses (which rank the effects of major plant components on a defined measure of system reliability) are detailed, as well as the component-failure-rate data base used to derive them. The contractor is ARINC Research Corp. *EPRI Project Manager: Jerome Weiss*

**Background Study of Liner Fusion Systems for Transmuting Fission Reactor Wastes**

AP-1644 Final Report (RP921-1); $10.50

The potential of using liner fusion systems for the transmutation of selected fission wastes was evaluated. This report discusses system performance requirements, concepts for some of the major subsystems, plasma physics considerations, problems with liquid liner-blanket systems for waste transmuters. Two plasma confinement configurations were studied. The contractor is General Atomic Co. *EPRI Project Manager: N. A. Amherd*

**Binary Module Test**

AP-1645 Final Report (RP1094); $7.25

A study was conducted to determine the overall performance characteristics of a binary module in geothermal service. The module was configured to be 1% of a commercial-size 50-MW (e) binary-cycle geothermal power plant; its design was based on state-of-the-art heat exchanger technology. Tests examined the operation of the module under supercritical boiling conditions while using isobutane and a mixture of isobutane and isopentane as the secondary working fluid. Actual performance was compared with predicted performance. The contractors are J. R. Schilling; Colley Engineers & Constructors, Inc.; and PFR Engineering Systems, Inc. *EPRI Project Manager: V. W. Roberts*

**Northeast Coal Utilization Program: Phase 2**

AP-1671 Final Report (RP1078); $7.25

This report documents the activities of a group of northeastern utilities investigating the introduction of coal liquefaction as a source of the liquid fuel needed for power generation in the region. Liquefaction by hydrogenation using the H-Coal, Exxon Donor Solvent, and SRC-II processes is the focus of general studies related to technology and economics, commercial project development, and plant siting. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: H. E. Lebowitz*

**High-Reliability Gas Turbine Combined-Cycle Development Program: Phase 1**

AP-1681-SY Summary Report (RP1187-3); $3.50

A study was initiated to develop a new centerline design for a combustion turbine that would have sufficient reliability for baseload service in a combined-cycle plant. This report reviews the six Phase 1 tasks, discusses the approach and methods used, and summarizes the trade-offs and conclusions. The contractor is General Electric Co. *EPRI Project Manager: R. L. Duncan*

**Test and Evaluation of Methanol in a Gas Turbine System**

AP-1712 Final Report (RP988-1); $9.50

A test was conducted to determine the effects of burning methanol in a utility gas turbine operating in peaking-type service; emissions, performance, and effects on engine and fuel-system hardware were evaluated. In the test, methanol was burned for 523 hours in one engine of a 52-MW (e) base-load-rated twin-engine installation. Performance and emission results from the methanol-fired engine were compared with results from its twin, which burned petroleum distillate fuel. The contractor is Southern California Edison Co. *EPRI Project Managers: R. L. Duncan and Henry Schreiber*

**Electric Utility Solar Energy Activities: 1980 Survey**

AP-1713-SR Special Report; $10.50

Solar energy activities sponsored by U.S. electric utilities were surveyed. This report presents brief descriptions of 839 projects conducted by 236 utilities. It also includes a list of projects by category, a statistical summary, and a list of available project reports. *EPRI Project Manager: E. A. DeMeo*

## COAL COMBUSTION SYSTEMS

**Impact of Coal Cleaning on the Cost of New Coal-Fired Power Generation**

CS-1622 Final Report (RP1180-2); $13.50

This economic study of seven hypothetical cases examines the impact of physical coal cleaning on power generation costs at coal-fired power plants with wet flue gas desulfurization systems. Raw, partially cleaned, and intensively cleaned coals were assessed for each case. This report includes case-by-case coal-cleaning, transportation, and power plant design data and cost estimates; technical descriptions of the coal-cleaning schemes used; and overall power generation costs. Coal washability data are presented in an appendix. The contractor is Bechtel National, Inc. *EPRI Project Managers: K. L. Clifford and C. R. McGowin*

**Investigation of Field Test Procedures for Large Fans**

CS-1651 Final Report (RP1649-5); $5.25

An ASME performance test code committee has suggested field test procedures for determining the performance of large, power-generation-type mechanical draft fans. This project investigated the feasibility of those procedures, as well as the suitability of certain velocity probes and electronic instrumentation for use under field conditions. Extensive field tests on a forced-draft fan and an induced-draft fan were conducted to aid in verifying and improving the fan test code. A computer code to assist in reducing the data was developed. The contractor is the University of Akron. *EPRI Project Manager: I. A. Diaz-Tous*

**Corrosion Problems in Coal-Fired Boiler Superheater and Reheater Tubes: Fireside Corrosion**

CS-1653 Final Report (RP644-1); $16.00

This report describes an effort to develop improved alloys for superheater and reheater tubes in direct-coal-fired boilers and to evaluate materials for use at higher-than-normal temperatures. A broad literature review of fireside corrosion studies was conducted, and 56 alloys and high-temperature coatings were tested in a laboratory environment similar to that of a corrosive-coal-burning furnace. Results on the corrosion mechanism and on factors important in determining corrosion resistance are detailed. The contractor is Foster Wheeler Development Corp. *EPRI Project Manager: John Stringer*

**Investigation of Numerical Modeling Techniques for Recirculating Flows**

CS-1665 Final Report, Parts 1 and 2 (RP901-1); $10.50

This report describes an effort to develop a three-dimensional numerical model for recirculating flows for the purpose of predicting plume recirculation in mechanical draft cooling towers. Part 1 presents a literature review and discusses prevailing views of turbulence modeling for various physical problems. A novel model is proposed that adapts the full Reynolds stress equations. Part 2 deals with the costs of numerical solution. Several promising cost-reduction methods are described. The contractor is Envirodyne Ltd. *EPRI Project Manager: J. A. Bartz*

**Development of an Advanced Concept of Dry-Wet Cooling of Power Generating Plants**

CS-1668 Interim Report (RP422-3); $6.50

This report describes the design of a facility being constructed to test an advanced dry-wet cooling concept. The facility will be capable of condensing steam from a small house turbine at the rate of 60,000 lb/h while using only 25% of the water that would be required by a conventional evaporative cooling tower. The report also summarizes the various technical support studies that have been performed, including component testing and material selection studies, and discusses occupational and environmental safety and operations planning. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. A. Bartz*

**Economics of Four FGD Systems**

CS-1677 Final Report (RP1180-3); $8.75

This report presents technical and economic evaluations of four flue gas desulfurization systems: a conventional limestone scrubber, a cocurrent limestone scrubber, a Chiyoda Thoroughbred-121 limestone scrubber, and a Wellman-Lord scrubber. The general process and economic design criteria established to maintain consistency from case to case are documented, and detailed equipment lists are given for the systems. The contractor is Stearns-Roger Engineering Corp. *EPRI Project Managers: S. M. Dalton and T. M. Morasky*

**Studies on Mathematical Models for Characterizing Plume and Drift Behavior From Cooling Towers**

CS-1683 Interim Report (RP906-1);
Vol. 1, $7.25; Vol. 2, $7.25; Vol. 3, $9.50;
Vol. 4, $6.50; Vol. 5, $4.50

This report presents the results to date of an effort to develop, improve, and validate mathematical models of plume dispersion from individual and clustered mechanical- and natural-draft cooling towers. This effort is focusing on prediction of visible plume trajectory and deposition of saline droplet drift. The goal is to provide useful tools for assessing the environmental impact of cooling tower plumes. Volume 1 summarizes European research on cooling-tower-plume dispersion. Volume 2 presents an improved model for plumes from single natural-draft towers, and Volume 3 presents a new drift deposition model for such towers. In Volume 4 the single-source plume model for natural-draft cooling towers is generalized to multiple sources, and in Volume 5 this multiple-source plume model is extended to treat drift deposition. The contractors are Argonne National Laboratory and the University of Illinois. *EPRI Project Manager: J. A. Bartz*

**1980 National Conference and Workshop on Coal Freezing**

WS-80-119 Conference/Workshop Proceedings; $11.25

A two-day national conference and workshop on the problems of coal freezing was held in spring 1980. This report presents formal papers, discussion summaries, and conclusions for the five conference topics: test procedures and standards for frozen coal, transportation problems of frozen coal, freeze-conditioning additives, consumer perspectives on frozen-coal problems, and methods of unloading frozen coal. The report also includes available material from a 1979 seminar on frozen-coal problems. *EPRI Project Manager: I. A. Diaz-Tous*

## ELECTRICAL SYSTEMS

**Determination of Synchronous Machine Stability Study Constants**

EL-1424 Final Report, Vol. 2 (RP997-2); $19.00

This report describes work to develop generator model parameters by using frequency response techniques. Data for two different 500-MW generators were gathered from tests of standstill, on-line, and rated-speed open-circuit frequency response; dc inductance; 60-Hz field impedance; and line-switching. The relative merits of generator models computed from standstill and on-line frequency response tests, stator decrement tests, and sudden-short-circuit tests were assessed, and model recommendations were made. The contractor is Ontario Hydro. *EPRI Project Managers: P. M. Anderson, D. T. Bewley, and J C. White*

**Study of Arc By-products in Gas-Insulated Equipment**

EL-1646 Final Report (RP1204-1); $5.75

A literature survey and a test program were conducted to develop a data base on $SF_6$ decomposition products generated by electric discharges in gas-insulated equipment. Another objective was to develop an analytic capability for utilities for incipient and actual fault analysis of $SF_6$-insulated equipment. This report describes the test fixtures (which represented sections of an $SF_6$-insulated bus), the arcing tests, the analytic methods used, and the nature of the gaseous and solid by-products observed. The contractor is Gould–Brown Boveri, Inc. *EPRI Project Manager: V. H. Tahiliani*

**Development of a New Type of Nonlinear Resistance Valve Block for Surge Arresters**

EL-1647 Final Report (RP425-1); $5.75

An investigation of how chemical composition and processing variables affect the electrical and physical characteristics of metal oxide varistors is presented. Various chemical compositions were studied, and the effects of various materials on the varistors' leakage current, discharge voltage, and energy-handling capability were evaluated. A scanning electron microscope, an energy-dispersive X-ray unit, and ultrasonic analysis were used to study the varistors' physical structure and characteristics. The contractor is McGraw-Edison Co. *EPRI Project Managers: V. H. Tahiliani and R. E. Kennon*

**Area Control Simulator Program**

EL-1648 Final Report (RP1048-4); Vol. 1, $3.50; Vol. 2, $3.50; Vol. 3, $4.50; Vol. 4, $2.75

Volume 1 discusses power system modeling and describes and illustrates the capabilities of a single-area generation control simulator developed in this project. The subsystems modeled include the nuclear, fossil fuel, hydro, and combustion turbine prime mover subroutines. Details are provided on typical control structures, required system data, and the load dispatch office monitoring and control algorithms. Volume 2, a programming manual, describes the simulator's overall program structure, subroutines, and use. It describes the assembling of a case study and discusses the use of input-output features, automatic generation control, simulator interfaces, and time synchronization. Volume 3 presents a program listing of the simulator, including all data sets, subroutines, and functions. Comments and instructions are given throughout. Volume 4 summarizes the development of a multiarea power system simulation model. The contractor is Philadelphia Electric Co. *EPRI Project Manager: C. J. Frank*

**Development of an Ionization-type Gas Density Monitor**
EL-1652 Final Report (RP1768-1); $2.75

This report describes a battery-operated electric gas density monitor developed for service in $SF_6$ gas-insulated substation equipment and transmission cable applications. Density measurement using an alpha ionization approach is detailed. The contractor is Sigma Research, Inc. *EPRI Project Manager: V. H. Tahiliani*

**Pool Daily Fuel Scheduling**
EL-1659 Final Report (RP1048-5); Vol. 1, $7.25; Vol. 2, $8.75; Vol. 3, $16.00

This report describes R&D on methods for power pool daily fuel scheduling. Volume 1 describes a potential scheduling procedure based on a combination of two approaches—a search approach and a mixed-integer linear programming approach—and presents the results of tests of each method. It also identifies a number of special scheduling problems and makes recommendations for future work. Volume 2 describes the organization and structure of prototype computer programs (coded in FORTRAN for testing and evaluation purposes) of the two approaches. It discusses the layout and function of data files and presents sample outputs and test data. Volume 3 contains the FORTRAN listings of all the programs developed during this project. The contractor is Power Technologies, Inc. *EPRI Project Manager: C. J. Frank*

**Dielectric Testing of Polysil for Inexpensive Underground Distribution and Transmission**
EL-1737 Final Report (TPS77-757); $2.75

This report presents the results of a study to determine the bulk dielectric properties of Polysil and to assess the feasibility of using it as an inexpensive dielectric for underground distribution and transmission. Polysil castings (using methyl mechacrylate or polyester-polystyrene as a binder) with embedded electrodes were made in sizes ranging from 8 to 13,000 lb. Statistical analyses performed on over 200 test specimens are given, as well as design curves for Polysil as an underground insulating material. The contractor is Lindsey Industries, Inc. *EPRI Project Manager: Mario Rabinowitz*

## ENERGY ANALYSIS AND ENVIRONMENT

**Coal Resource Information**
EA-673 Final Report, Vol. 1 (RP868-1); $5.25

This volume presents the results of a 1977 survey to identify the types of coal resource information needed by coal producers and users. Information requirements for seven categories of production and use are covered: extraction; beneficiation; transporting, loading, and storage; carbonization; combustion; gasification; and liquefaction. The contractor is ICF Incorporated. *EPRI Project Manager: J. B. Platt*

**Coal Resource Information**
EA-673 Final Report, Vol. 2 (RP868-1); Part 1, $5.75; Part 2, $19.00; Part 3, $16.50

This volume is a three-part review of coal resource information published through early 1977. Part 1 summarizes and evaluates 20 major national and regional coal resource documents; it also provides brief descriptions of several ongoing (as of 1977) related research projects. Part 2 presents an annotated bibliography of some 350 major sources of coal resource information. Each source is analyzed in terms of the types of information it contains, the raw data and statistical techniques used to develop that information, and the key definitions and assumptions used. Part 3 is a bibliography of over 4300 coal resource documents on the location, quality, and mineability of U.S. coal. The entries are arranged by state and cross-indexed by other geographic designations. A list of bibliographies is also included. The contractor is ICF Incorporated. *EPRI Project Manager: J. B. Platt*

**Coal Mining Cost Model**
EA-1273 Final Report (RP1009-2); Vol. 1, $11.25; Vol. 2, $5.25; Vol. 3, $8.75; Vol. 4, $5.25

The revised EPRI underground and surface coal mining cost models represent a computerized process engineering approach to production cost and mining requirement analysis. The updated models, which contain expanded data bases reflecting a mid-1980 base year for cost items, can be used to estimate typical preproduction and production capital and operating costs for existing or proposed mining projects. Volume 1 documents the underground coal mining cost model, describing the process engineering and financial analysis procedures it employs; Volume 2 presents a user's guide for that model. Volume 3 documents the surface coal mining cost model, and Volume 4 presents a user's guide. Each model has been designed for use in a batch or an interactive processing mode, and each user's guide provides computer application guidelines and test cases for both the batch and interactive versions. The contractor is NUS Corporation. *EPRI Project Manager: T. E. Browne*

**Regional Air Quality Studies: Needs and Priorities**
EA-1650-SR Special Report; $4.50

On the basis of an assessment of utility industry needs, priorities have been established for EPRI's regional air quality studies (RAQS) and a five-year research plan has been developed. Four problem areas were addressed in the planning effort: $SO_X$ and $NO_X$ chemistry, acid precipitation, trace elements and fine particles, and visibility. The research needs common to all four areas were identified, as well as special requirements. The plan also addresses the desirability of coordinating RAQS with similar research that is being funded by other agencies. *EPRI Project Manager: G. R. Hilst*

**Regional Load Curve Models: Specification and Estimation of the DRI Model**
EA-1672 Final Report, Vol. 1 (RP1008-1); $9.50

This report describes the conceptualization, specification, and estimation of the Data Resources, Inc. (DRI) model, a monthly time-series–econometric model for forecasting hourly electric loads on a regional level. The contractor is Data Resources, Inc. *EPRI Project Managers: Ahmad Faruqui and A. G. Lawrence*

## ENERGY MANAGEMENT AND UTILIZATION

**Molten Carbonate Fuel Cell System Verification and Scale-up**
EM-1481 Interim Report (RP1273-1); $4.50

This report presents results from the first 16 months of a project to demonstrate the operability of a molten carbonate cell stack, an advanced fuel processor, and other critical system components in a subscale power plant. Two technical tasks—testing a nominal 2-kW stack design developed in other EPRI work and testing a nominal 2-kW stack at elevated pressures—are outlined. The contractor is United Technologies Corp. *EPRI Project Manager: E. A. Gillis*

**Improved FCG-1 Cell Technology**
EM-1566 Final Report (RP842-5); $3.50

This report describes the development and testing of a lower-cost, more durable fuel cell stack configuration aimed at facilitating the commercialization of dispersed fuel cell power plants. Improvements were made in ribbed-substrate acid cell repeating parts, and full-size ribbed-substrate stack components incorporating more stable materials were evaluated under conditions of increased pressure and temperature. The contractor is United Technologies Corp. *EPRI Project Manager: E. A. Gillis*

**Solar-Heated Hot Water Instrumentation Project for EPRI Headquarters Complex**
EM-1654 Final Report (RP1191-1); $7.25

Detailed load and performance data are presented for a solar-assisted hot water preheat system supplying a portion of the water needs at EPRI headquarters in Palo Alto, California. The report assesses the low-cost monitoring system employed, describes the sensor hardware, and discusses the implications of the data obtained. The contractor is Pacific Sun Inc. *EPRI Project Manager: G. G. Purcell*

**Fuel Cell Power Plant Integrated Systems Evaluation**
EM-1670 Final Report (RP1085-1); $9.50

Cost and performance analyses of molten carbonate fuel cell power plants were performed to determine integrated design configurations for large (675-MW) central coal-fired power stations and small (5-MW) dispersed generation plants fueled by oil. The contractor is General Electric Co. *EPRI Project Manager: B. R. Mehta*

**Simplified Methodology for Economic Screening of Potential Low-Head, Small-Capacity Hydroelectric Sites**
EM-1679 Final Report (RP1199-5); $8.75

A simplified methodology for first-level evaluation of potential low-head, small-capacity hydroelectric sites is presented in the form of a manual. Procedures for estimating power output and capacity and for making an economic and financial analysis are described. Major environmental and institutional factors that may affect a project are outlined. Examples illustrating the use of the manual are included, and appendixes provide background information on hydroelectric development. The contractor is Tudor Engineering Co. *EPRI Project Manager: Antonio Ferreira*

**Performance Monitoring of Ground-Coupled, Solar-Assisted Heat Pump Systems**

EM-1697 Interim Report (RP1191-6); $2.75

In a project involving three Oklahoma Gas and Electric Co. demonstration houses, the performance of a ground-coupled, solar-assisted heat pump system is being compared with that of a nonsolar ground-coupled heat pump and that of a conventional air-source heat pump. This report outlines the project objectives, describes the heating, ventilating, and air conditioning systems and the data acquisition systems, and presents early findings. The contractor is Oklahoma State University. *EPRI Project Manager: G. G. Purcell*

**Electromagnetic Testing of Ceramic Materials: A Feasibility Study**

EM-1698 Final Report (RP109-5); $3.50

The feasibility of using an electromagnetic technique to detect defects in beta-aluminas and other ceramic materials was investigated. The anomalously large crack signals and lift-off signals obtained when using focused-field electromagnetic testing methods on certain ceramics were examined, and a method for enhancing crack detection in one type of ionic ceramic was proposed. The contractor is The Reluxtrol Co. *EPRI Project Manager: Barry Syrett*

**Development of the Adiabatic Reformer to Process No. 2 Fuel Oil and Coal-Derived Liquid Fuels**

EM-1701 Interim Report (RP1041-4); $4.50

This report describes the development and testing of sulfur-tolerant catalysts for processing No. 2 fuel oil and selected coal-derived distillates at conditions compatible with fuel cell operation. The impacts of these catalysts on power plant costs and efficiency are assessed, and typical operating characteristics of an adiabatic reformer are presented. The contractor is United Technologies Corp. *EPRI Project Manager: E. A. Gillis*

## NUCLEAR POWER

**OZMA: A Code to Calculate Resonance Reaction Rates in Reactor Lattices Using Resonance Profile Tabulations**

NP-926 Topical Report (RP709-1); $4.50

The OZMA computer code solves the neutron transport equation for a reactor lattice unit cell at energies that lie in the resolved resonance regions of the lattice nuclides. Spherical, slab, cylindrical, square, and hexagonal geometries can be handled. This report—primarily an OZMA user's manual—gives a description of the code, input instructions, sample input, and details of the output. The contractor is Technion—Israel Institute of Technology. *EPRI Project Manager: Odelli Ozer*

**Analysis of Steam Chugging Phenomena**

NP-1305 Final Report (RP1067-1); Vol. 1, $6.50; Vol. 4, $6.50

Volume 1 presents thermal-hydraulic models that simulate steam chugging phenomena and are based on fundamental mass, momentum, and energy conservation laws. Computer codes were written to describe random internal chugging, gas dynamics, and multivent phenomena in the downcomer pipes and supply lines; temperature distributions in the pool water; area changes and condensation rates at the moving free surface; and response of the tank walls. Results were compared with experimental data. Volume 4 serves as a user's manual for SAMPAC1, a hydrodynamic pool response computer program developed in this project. The program is designed to simulate the motion of the fluid and the steam-water interface during rapid condensation events in LWR steam suppression pools. Only the two-dimensional free-surface fluid motion is calculated and presented here. The contractor is Jaycor. *EPRI Project Manager: J. P. Sursock*

**PWR FLECHT SEASET 161-Rod Bundle Flow Blockage Task**

NP-1458 Interim Report (RP959-1); $8.25

This report presents test plans for the 161-rod bundle flow blockage task of the full-length emergency cooling heat transfer–separate effects and system effects tests (FLECHT SEASET). The data requirements, instrumentation plan, test facility, test matrix, and data reduction and analysis plans are described. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: K. H. Sun*

**ABAQUS-ND: A Finite Element Code for Nonlinear Dynamic Analysis**

NP-1552-CCM Computer Code Manual, Vol. 4 (RP1324-3, RP964-5); $7.25

ABAQUS-ND is a general-purpose finite element computer code for the routine solution of nonlinear problems, primarily involving structural response. This volume describes the theoretical concepts on which the code is based, as well as the formulations and algorithms implemented in it. The contractor is Hibbitt & Karlsson, Inc. *EPRI Project Manager: H. T. Tang*

**Fast Breeder Blanket Facility**

NP-1657 Interim Report (RP514-1); $4.50

A fast breeder blanket facility has been constructed at Purdue University for experiments on prototypical blankets of various compositions and configurations. This report presents a detailed description of the facility, discusses special safety considerations factored into the design, and summarizes criticality calculations made to ensure the facility's safety under both normal and accidental flooding conditions. It also presents examples of preliminary experimental measurements. The contractor is Purdue University. *EPRI Project Manager: B. R. Sehgal*

**Analysis of Radiation Embrittlement Reference Toughness Curves**

NP-1661 Final Report (RP886-1); $5.25

This report describes a project to evaluate and develop techniques for measuring and predicting radiation damage. Three major tasks are detailed: statistical analysis and development of reference fracture toughness curves, evaluation of fracture toughness data from surveillance specimens, and radiation damage analysis and modeling. The contractor is Fracture Control Corp. *EPRI Project Manager: T. U. Marston*

**Evaluation of Flow Redistribution Due to Flow Blockage in Rod Bundles, Using COBRA Code Simulation**

NP-1662 Final Report (RP1380-2); $4.50

The feasibility of using the COBRA IV subchannel computer code to analyze flow blockage in rod bundles during a loss-of-coolant accident was examined. The code was used to simulate flow redistribution caused by sleeve blockages and plate blockages. Sensitivity studies were conducted to determine the effects of several factors on flow redistribution. Pressure drop due to sleeve blockage was also calculated for several blockage configurations. The contractor is NUS Corporation. *EPRI Project Manager: K. H. Sun*

**Assessment of Exposure Fire Hazards to Cable Trays**

NP-1675 Interim Report (RP1165-1-1); $4.50

This report presents a method (applicable to hand-held programmable calculators) for initially assessing fire risks in an enclosed room that contains cable with combustible insulation. The design, implementation, and results of an experimental test program are described. A methodology is proposed by which the test results can be applied to the evaluation of exposure fire hazards to utility cable tray installations. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: R. E. Swanson*

**Thermal-Hydraulic Analysis of the Combustion Engineering Series 67 Steam Generator**

NP-1678 Final Report (RPS130-1); $7.25

Results of a thermal-hydraulic analysis of the Combustion Engineering Series 67 recirculating steam generator are presented. THIRST—a three-dimensional, steady-state, incompressible, homogeneous, two-phase-flow computer code—was used to model the steam generator at 100%, 50%, and 20% of full operating power. The code methodology is discussed, and the assumptions, operating conditions, and empirical correlations are detailed. The contractor is Atomic Energy of Canada Ltd. *EPRI Project Manager: D. A. Steininger*

**SPASM: A Computer Code for Monte Carlo System Evaluation**

NP-1685 Final Report (RP1233-1); $2.75

This report is one in a series on the development of computer codes for use in quantitative fault tree analysis. It describes SPASM, a computer code in the WAM family that evaluates the top-of-the-tree distribution of system success and failure frequency by means of Monte Carlo simulation. SPASM can be used independently or in conjunction with WAMCUT. The contractor is Science Applications, Inc. *EPRI Project Manager: G. S. Lellouche*

**Technique for Inserting Controlled Flaws in Heavy-Section Weldments**

NP-1686 Final Report (RP1245-2); $4.50

Welding techniques were developed that enable placement of fatigue crack flaws in heavy-section weldments at desired through-wall locations. Procedures were demonstrated for fabricating sealed inserts containing fatigue crack flaws of known size and orientation and for implanting such insets in a heavy-section weldment without altering the flaws. A 280-mm-thick weldment containing five fatigue crack flaws was fabricated and metallographically sectioned to provide final validation of the procedures. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. R. Quinn*

**STRAP: Steam Turbine Rotor Analysis Program**

NP-1687 Computer Code Manual, Part 1 (RP502); $3.50

This manual presents a general overview of a computerized rotor-lifetime-prediction system called STRAP. This system consists of three computer programs: a preprocessor (PPMESH), a postprocessor (FRAC), and an ultrasonic inspection data analysis subroutine (CLUELP). A commercially available, general-purpose finite element analysis code (ANSYS) is used as an intermediate link between the PPMESH and FRAC programs. The contractors are Battelle, Columbus Laboratories and Southwest Research Institute. *EPRI Project Manager: F. E. Gelhaus*

**Impact of Operational Experience on Research and Development**

NP-1689-SR Special Report; $2.75

The gradual accumulation of operating-experience data from nuclear power plants is having a perceptible impact on the direction of research and development. This report discusses the impact in four areas: an increased awareness of systems interaction, the importance of operational data for code qualification, a sharper focus on separate effects, and the importance of well-defined scaled experiments. Illustrations from EPRI projects are presented. *EPRI Project Manager: A. G. Adamantiades*

**Nondestructive Evaluation Program Progress in 1980**

NP-1690-SR Special Report; $16.50

This special report, the second in a series of annual progress reports, presents a comprehensive review of EPRI efforts in the area of nondestructive evaluation (NDE), with emphasis on the development of improved inspection technology for LWRs. Contractor-supplied technical summaries of current projects make up the main body of the report. An organizational plan of the NDE program is also included. *EPRI Project Manager: G. J. Dau*

**Heat Transfer Above the Two-Phase Mixture Level Under Core-Uncovering Conditions in a 336-Rod Bundle**

NP-1692 Interim Report (RP1760-1); Vol. 1, $6.50; Vol. 2, $25.75

Volume 1 presents the results of 22 constant-boil-off tests performed on a 336-rod bundle in the Westinghouse G-2 loop test facility. A description of the test facility, instrumentation, and procedure is included, along with calculated data on the bundle mixture levels as a function of time and data on a representative sample of rod heat fluxes. Volume 2 presents plots of the tests. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: K. H. Sun*

**Neutron Total and Capture Cross Sections of $^{232}$Th From 0.006 to 18 eV**

NP-1704 Final Report (RP511-1-4); $5.75

This report presents results from a study that measured the total and capture cross sections of $^{232}$Th, as well as their energy dependences, in the energy range from 0.006 to 18 eV. The contractor is Rensselaer Polytechnic Institute. *EPRI Project Manager: Odelli Ozer*

## PLANNING

**1981–1985 Research and Development Program Plan: Program Descriptions**

P-1726-SR Special Report; $18.00

This document describes the objectives and rationale of EPRI's R&D program for the coming five-year period. Forty programs, organized by EPRI technical division, are described in terms of their major objectives, importance to the electric utility industry, motivating issues, technical impediments, anticipated key events, and planned expenditures over the next five years.

**1981 Research and Development Program Plan**

P-1727-SR Special Report; $10.50

This document summarizes information on the 1981 EPRI R&D program essential for management review and operation. Each of EPRI's 40 technical programs is described in terms of structure, overall goals, principal content, major projects, and major objectives. In addition, the specific projects to be undertaken in each program during 1981 are identified, along with the overall performance milestones against which each program will be measured. A lsit of selected candidate projects that represent work priorities beyond 1981 is also presented.

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

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