Dimensions in Wind

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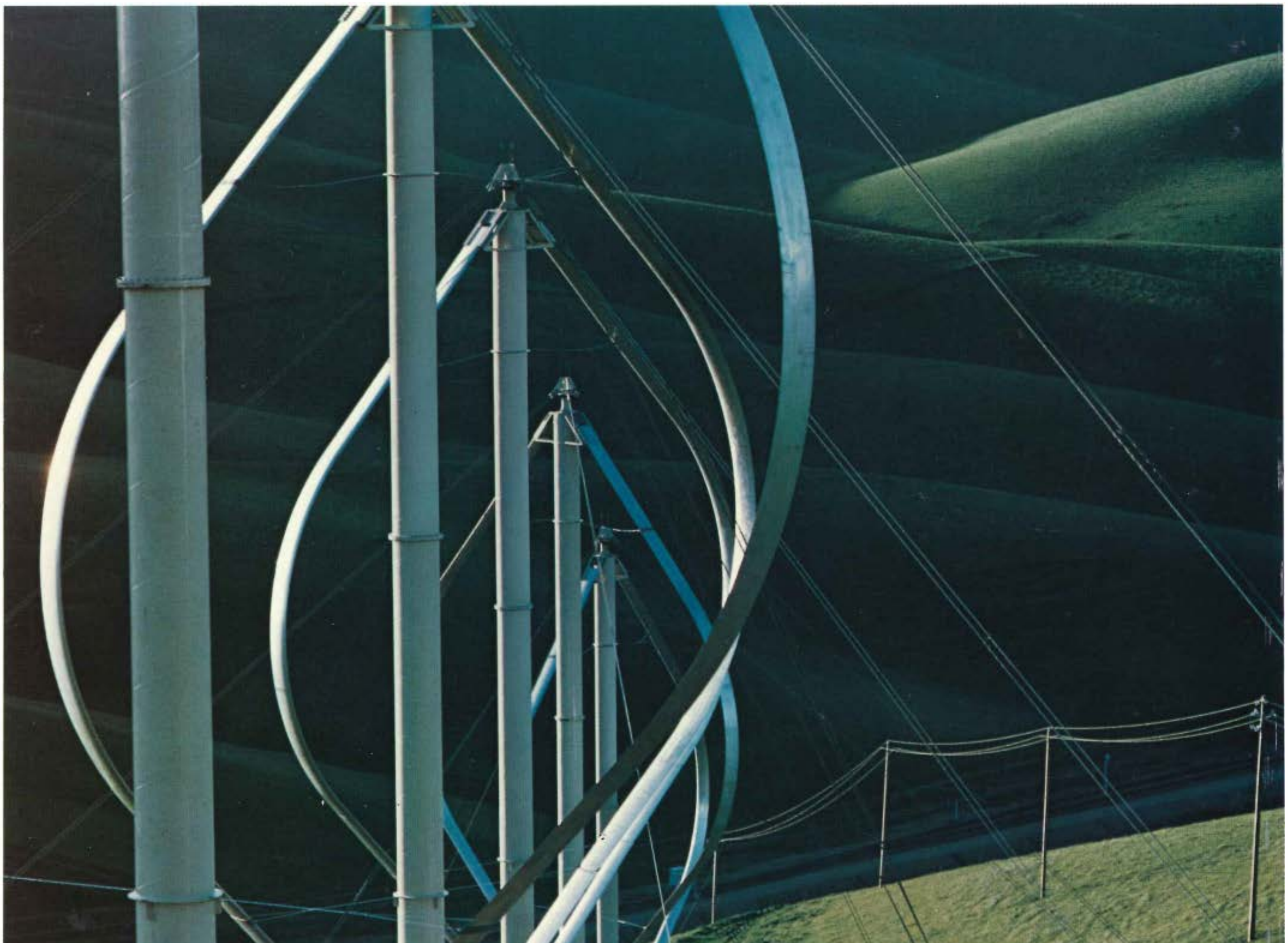

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EPRI JOURNAL Staff and Contributors
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John Kenton (Nuclear)

Graphics Consultant: Frank A. Rodriquez

Ray Schuster, Director
Communications Division

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

Cover: Vertical-axis machines are represented among the several thousand wind turbines that dot the landscape in northern California's Altamont Pass.

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Searching for the Fully Competitive Wind System

The goal of the Advanced Power Systems Division is to develop modular generating systems for the 1990s, with module sizes ranging from hundreds of kilowatts to hundreds of megawatts. The options range from gasification–combined-cycle systems that burn fossil fuels to solar- and wind-driven "farms" that use renewable energy resources. Not only are wind energy systems modular in overall capacity, but so are the individual modules—the wind turbines.

Over the last three or four years, we have worked closely with the federal government, individual utilities, and private developers to assess the technical and economic performance of first-generation wind systems. We have focused on the field evaluation of small (less than 100 kW) and large (greater than 1 MW) wind turbines and on economic evaluations of projected commercial units. In addition, we have defined siting criteria and sponsored the development of instrumentation to gain a more complete understanding of wind environments and their interaction with turbine rotors.

This month's lead article summarizes the status of our work and the lessons learned from our experience. Although we have not reached final conclusions, it appears that wind turbines in the intermediate capacity range—say, from 300 to 700 kW—have the best prospect of meeting the cost and availability requirements of electric utility ownership and operation. For units of a few hundred kilowatts, capital costs are now approaching the competitive level as fuel-displacement systems where oil and gas are used and where high, steady winds prevail. Cost reduction, coupled with better design bases developed from field measurements, should lead to fully competitive and reliable machines with reduced cut-in wind velocities and thus to broader geographic application.

Of course, we are not going to be correct in all our performance and economic projections. The costs of new systems often grow as we better understand them, and this irony demands early and continued screening of options. Working on systems that are competitive only at the margin—those supported by tax incentives—is not, in my judgment, the proper approach. The average price of electricity is forced to grow if this approach is taken.

Unfortunately, that is one effect of PURPA (Public Utility Regulatory Policies Act), insofar as electric utilities are required to purchase energy from cogenerators whose primary objectives are tax write-offs rather than reliable electricity supply. Let me expand on this point. Utilities buy such cogenerated energy at "avoided or marginal cost." This implies the highest price the cogenerator can negotiate, usually for intermittent, off-peak generation. The resultant pressure on utility rates is twofold: high cost for the cogenerated energy and reduced load factor for baseload generation (from more-economic units whose amortization is now spread across fewer kilowatthours).

In the near term this approach may produce some random successes and encourage some meaningful R&D. However, in the long term it works against truly substantial deployment of wind (and other renewable) energy systems. It is contradictory to the business ethic of the electric power industry, which has always been to reduce the unit cost of electricity.

Moreover, if renewable resource systems are not developed in a meaningful economic context, electric utilities could eventually lose control of the power generation end of the system.

If there is to be a significant, long-term commitment to renewable resource systems by electric utilities, reduced cost of service must be an attainable economic objective. Customer energy cost is therefore a key element of EPRI's R&D strategy, as well as the basis for assessing individual wind turbine developments.

Dwain F. Spencer

Dwain F. Spencer, Vice President
Advanced Power Systems

Authors and Articles

Contradictory trends in wind energy systems are making it difficult to define the mix of R&D that is both affordable today and most likely to produce useful results for electric utility application in the years ahead. **Wind Power: A Question of Scale** (page 6) reviews the markedly different technologies of large and small wind turbines and the equally contrasting business circumstances of their developers. To interpret these factors, *Journal* feature writer Taylor Moore turned to three R&D managers of the Renewable Resources Systems Department in EPRI's Advanced Power Systems Division.

Frank Goodman, Jr., became project manager for wind power shortly after joining the Institute in August 1979. Previously with the Los Angeles Department of Water & Power for four years, he worked successively in system planning and in assessments of wind, solar, and biomass energy technologies. Goodman holds BS, MS, and PhD degrees in electrical engineering from the University of California at Santa Barbara.

Edgar DeMeo has managed the Solar Power Systems Program since January 1980, guiding EPRI research in wind, solar-thermal, photovoltaic, and biomass energy technologies. He joined the Institute in August 1976 to manage research in photovoltaic and wind energy. DeMeo's earlier work included six years on the engineering research faculty at Brown University and two years as an instructor in the science department of the U.S. Naval Academy. An electrical engineering graduate of Rensselaer Polytechnic Institute, DeMeo later earned MS and PhD degrees at Brown.

John Cummings came to EPRI in January 1975, became manager of the solar energy program in 1976, and was named director of the Renewable Resources Systems Department in 1979. He was previously with Itek Corp. for two years, directing its energy program and developing business plans for solar and other new energy technologies, and in 1972 he was a technical analyst with the Atomic Energy Commission. Cummings graduated in engineering from the U.S. Coast Guard Academy. He later earned MS and PhD degrees in physics at the University of Arizona, as well as an MBA while on the faculty there.

■

Insulators, of all things—ubiquitous but mundane and electrically passive—have become one of EPRI's best success stories. Actually, the success is a polymer concrete called Polysil, licensed to nine manufacturers in the United States and abroad; and insulators are simply the first and most obvious product on the market. **Polysil Poised for the Marketplace** (page 17) describes the production and performance features that should be attractive in a variety of electrical parts and apparatus. Science writer Stephen Tracy wrote the article, guided by John Dunlap of EPRI's Electrical Systems Division.

Dunlap, a project manager in the Overhead Transmission Lines Program since February 1979, is responsible for the field proof tests begun when Polysil components were introduced in 1978. Dunlap was formerly with Florida Power & Light Co., where he worked for 21 years, ultimately as supervisor for the redesign and conversion of transmission lines to higher voltages. He graduated in electrical engineering from the University of Tennessee.

■

Embargo-driven oil prices in 1974 created a near-term need for coal liquefaction technology, even when its R&D horizon looked more like mid term to long term. Today, with a softer oil market, the need and the R&D status both appear to be mid term. **Narrowing the Field in Coal Liquefaction** (page 22) traces developments of the past 10 years and describes the promising processes that are being tested at pilot plant scale. The *Journal*'s Taylor Moore wrote the article, with the assistance of Howard Lebowitz, manager of EPRI's Clean Liquid and Solid Fuels Program.

Lebowitz came to EPRI in December 1975 as a project manager; he was named technical manager in 1980 and program manager in 1981. Coal liquefaction is his long-time special interest; he worked for Conoco Coal Development Co. from 1968 to 1975, becoming group leader in liquefaction R&D. Lebowitz graduated in chemical engineering from Pennsylvania State University.

■

Conservationists often seem to lead embattled lives, engaged at every turn in adversary struggles against society's entrenched thinking and wasteful practices. Not so with Grant Thompson, director of the energy program of The Conservation Foundation and member of EPRI's Advisory Council. Confronting issues rather than people, this environmental lawyer believes that market-level prices usually encourage resource conservation more efficiently than regulations can enforce it. **Grant Thompson: Pricing for Conservation** (page 28) was written by Ralph Whitaker, the *Journal*'s feature editor.

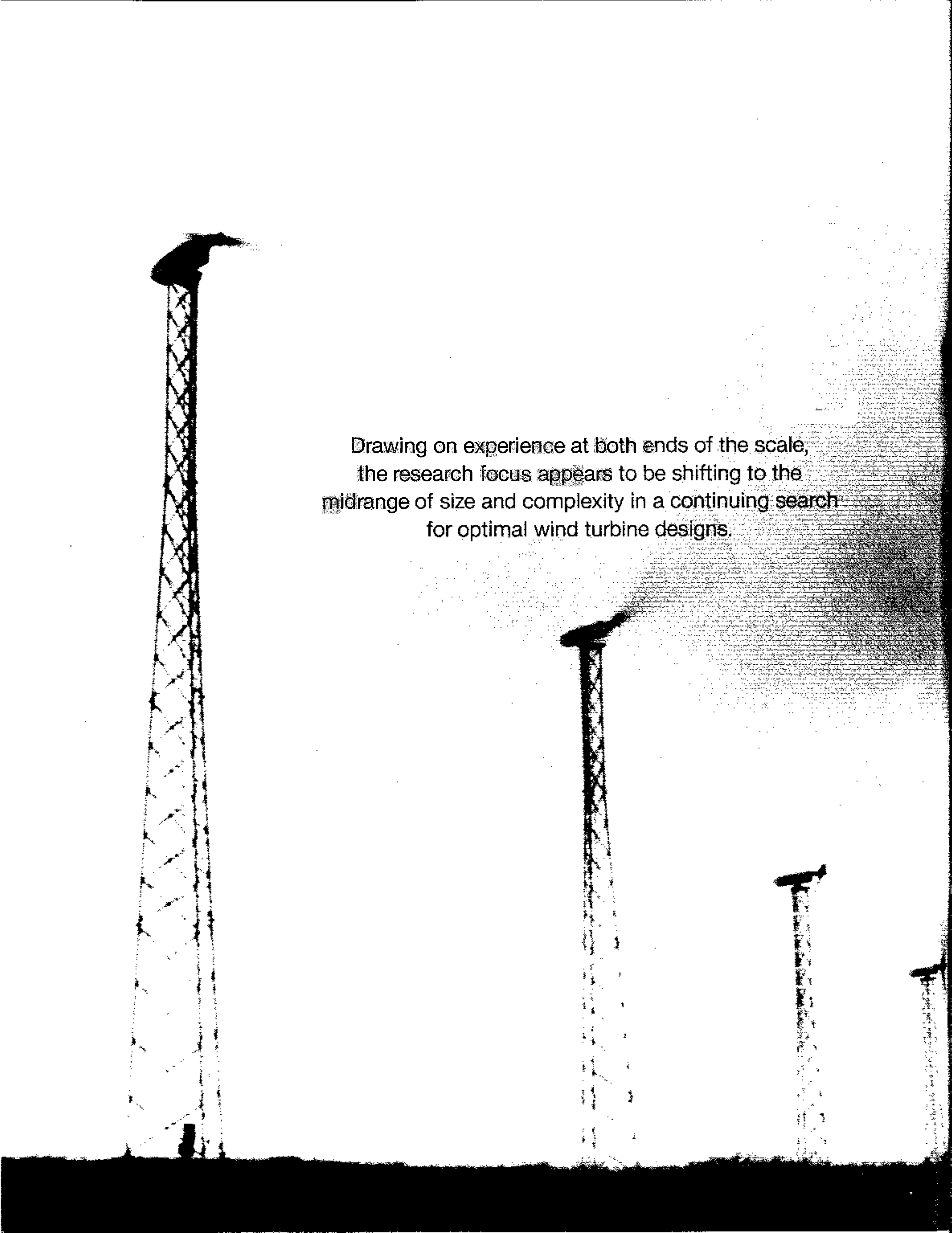
Goodman

DeMeo

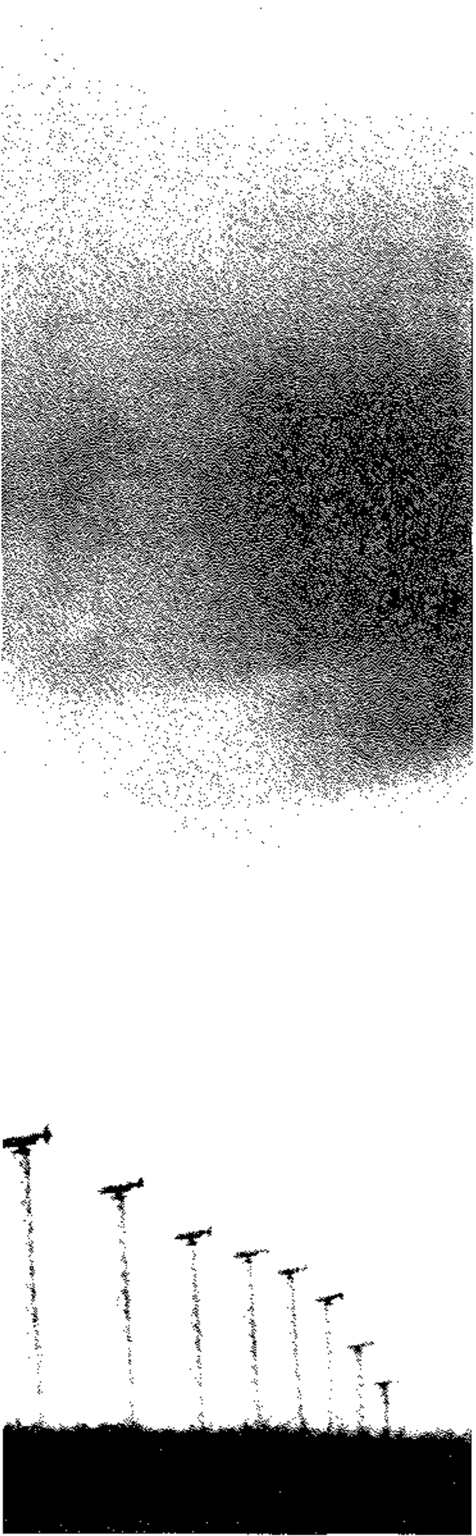
Cummings

Lebowitz

Dunlap



Drawing on experience at both ends of the scale, the research focus appears to be shifting to the midrange of size and complexity in a continuing search for optimal wind turbine designs.



In some of the more blustery parts of the country today, a new breed of developer is harvesting energy from the wind. Seen in the 1970s as a partial solution to the world's declining stock of fossil fuels, wind turbines for generating electricity are taking off less than a decade later. Independent power producers have placed in service several thousand wind turbines, ranging in size from 50 to 400 kW, in parts of California—plus dozens more in other states—to generate kilowatthours for sale to local utilities. In addition, half a dozen larger, megawatt-size turbines are producing energy as well as engineering data in a continuing R&D quest for advanced, economic wind machines.

Wind turbines at both ends of the scale have come a long way in a short time. Small turbines, generally equipped with rotors about 50 ft (15 m) long and employing conventional technology, are being installed in significant numbers because of recent laws and tax subsidies intended to encourage development of renewable energy sources. Turbines with rotors as long as 300 ft (91 m), with rotational axes 200–300 ft (61–91 m) off the ground, and of considerably more sophisticated design and construction have been developed mainly through a systematic national R&D effort led by federal agencies.

Economic, technical, and political forces have combined to push further into the future the time when large, megawatt-scale wind turbines may be considered as a commercial electric generating technology. World oil prices have fallen in recent years; utilities have experienced slower-than-expected growth in the demand for electricity; and dramatic shifts in both philosophy and funding priorities in energy technology have reflected the political changes in Washington.

With several experimental large turbines now operating, some of the funds and research attention that had been focused on them are shifting in the direction of their smaller cousins. Early operating experience with turbines of all sizes is highlighting the need for improved fundamental understanding of the effects of complex wind dynamics on the structural loading and fatigue life of these machines. Reducing such uncertainties will contribute toward development of optimal-size, commercially competitive wind machines for bulk power production.

Trade-offs in size

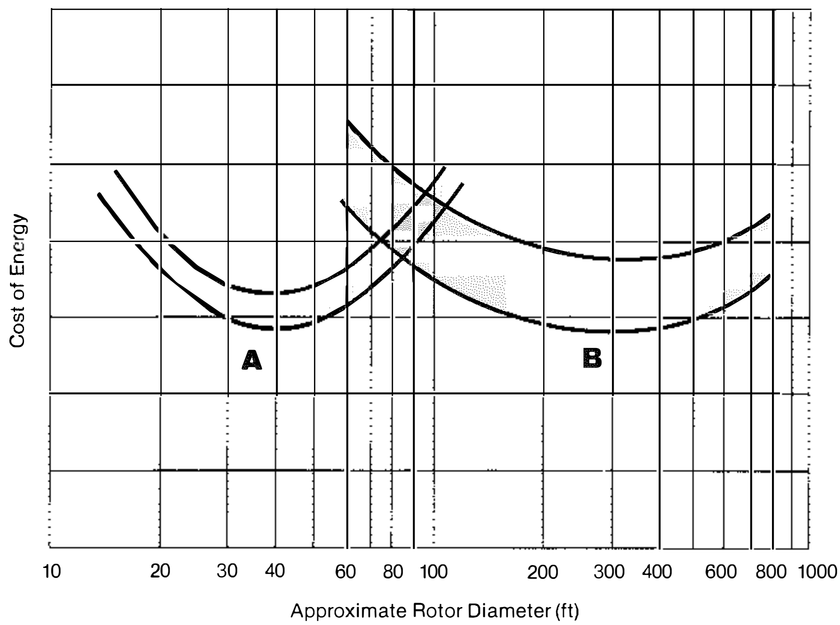
Wind turbines have advanced along several fronts in recent years: large machines, small machines, horizontal-axis machines, and vertical-axis machines. "From a design and reliability standpoint, some are good machines and some are bad," notes Frank Goodman, Jr., manager of EPRI's wind power projects in the Advanced Power Systems Division.

"The well-engineered machines have come from developers who have a firm understanding of the state of the art," says Goodman. "Problems that have been experienced with these machines have been manageable. Those built with insufficient attention to engineering, on the other hand, have been so plagued with breakdowns that excessive repairs and retrofits (or even total abandonment) have been necessary."

Aside from the basic mechanical configuration of a blade turning a gearbox and generator, wind turbines at opposite ends of the scale have little in common. Small machines, generally with a 50–150-kW generator rating and rather simple technical features, are being deployed in some regions by investor groups taking advantage of highly favorable tax incentives. The door for these developers was opened in 1978 with enactment of the Public Utility Regulatory Policies Act (PURPA), which requires utilities to pay rates for independently generated energy that are equivalent to the avoided cost of conventionally produced electricity. Most of the turbines installed to date by independent developers have been mainly the product of small manufacturers.

Researchers believe wind turbines may have limited economies of scale. At some level of size and complexity the economies of scale become increasingly offset by material mass and added protective devices. In this simplified representation, the optimal size ranges for small turbines **A** and large machines **B** are suggested by the lowest areas in the bands. The actual size range and designs that will eventually emerge as preferred for most utility applications have yet to be determined.

Simplified Hypothetical Cost and Size Trend



Large turbines rated at one or more megawatts, in contrast, incorporate advanced technology, such as hydraulic blade-pitch controls and computers; the few operating machines of this size are of an experimental nature. Federal agencies and a few utilities account for all deployment of megawatt-scale wind turbines.

The economics of wind turbines involve trade-offs between factors that tend to work in opposite directions as the scale of the technology increases. Economies of scale are driven by the wind power law of physics, which says the energy that can be extracted from the wind increases in proportion to the disk area swept by a turbine rotor and to the cube of the wind speed.

To a turbine designer, the wind power law argues for large rotors turning at sufficient heights to capture the stronger winds often found farther above the ground. The larger the rotor diameter and the stronger the wind, the more powerful can be the turbine generator. Clusters of large turbines maximize the amount of energy that can be generated from a given wind resource area. Thus, up to some point, the capital cost per kilowatt of rated generator output declines as size increases.

But there are also diseconomies of scale. In wind turbines, as with other technologies, increasing size implies increasing complexity; additional controls and devices are required to maintain reliability and prevent a turbine from damaging or destroying itself in extraordinary operating conditions. At some as yet unknown scale the cost of this added complexity begins to outweigh the economy of increasing scale.

Costs of operation and maintenance (O&M) complicate an abstract comparison of economics versus scale. O&M costs include scheduled and unscheduled repairs, replacement parts, and site personnel. Such costs are affected by both total field capacity and turbine reliability and size. For example, O&M costs for large turbines, although projected to be comparable to those of small turbines in mass deployment of mature designs, could be potentially very high if the reliability of key components does not meet design values. The failure of critical parts can put a turbine out of service for an extended period, and replacement costs for such items as rotors or drive shafts can spell the difference between economical operation and losing money.

Smaller, simpler wind turbines, on the other hand, contain fewer parts that can be more easily and less expensively replaced. For these machines, minimizing the frequency of repairs is the key to containing O&M costs.

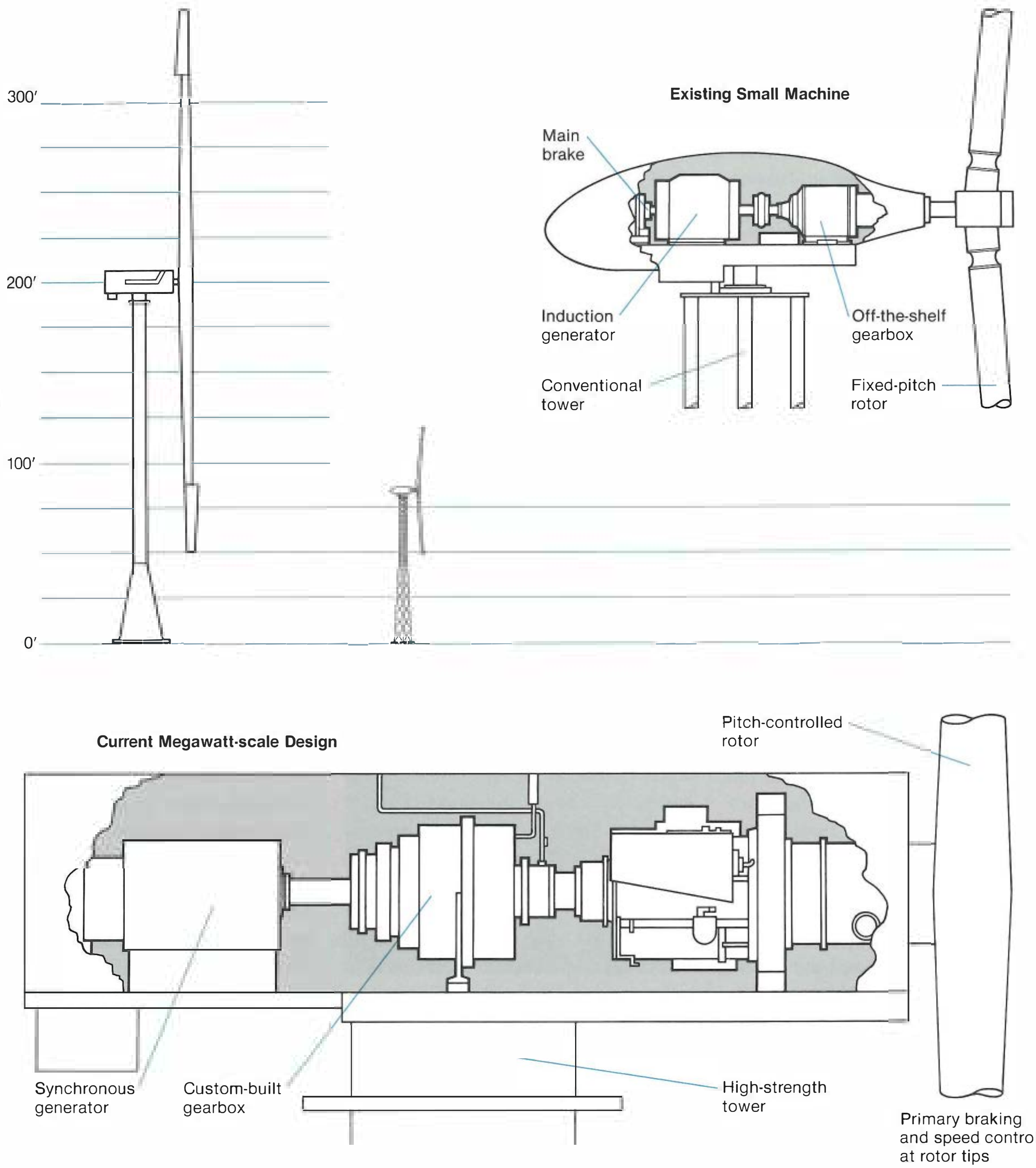
Partly as a result of the uncertainties associated with O&M costs in the absence of long-term operating experience, investment risks increase significantly as one moves up the technological scale. A single large wind turbine may cost \$10–\$15 million to install and have a projected reliability based entirely on estimates. The same magnitude of investment could install several hundred small turbines.

Insufficient operating experience has accumulated to confidently project O&M costs for mature wind turbines in any size range. So far, all wind turbines have experienced problems, and O&M costs have been excessive. Preliminary indications, however, suggest that O&M costs of less than 1¢/kWh may be achievable with both small and large turbines.

The interplay between the factors that influence wind turbine economics is directing R&D interest toward machines ranging from 200 kW to 1 MW. Moreover, this size range is better suited for R&D because the cost of experimentation is much less than that of megawatt-scale turbines. The optimal commercial

Wind Turbines—Comparative Characteristics

Megawatt-scale wind turbines are more than just bigger versions of the small machines now deployed in significant numbers in parts of the country. Their greater size and complexity require substantially more-sophisticated design and construction, including hydraulic rotor pitch controls and extensive protective devices. The R&D focus on advanced wind turbines is shifting to the midrange of scale; future machines will likely retain much of the simplicity of today's smaller machines but in scaled-up designs with selected innovations to enhance economic operation.



scale for advanced wind turbine technology remains to be determined, however.

The view that the optimal size for wind turbines for utility application may lie somewhere between small (50–150-kW) machines and multimegawatt designs is not universally held by wind energy experts. But developments at both ends of the scale suggest a convergence of economics and technology at or near the 1-MW level for the foreseeable future.

Clusters of small machines—popularly referred to as wind farms or wind parks—are already turning a profit for investors in California, Oregon, Texas, Montana, and New York. Improved versions of these machines, with increased reliability and energy production, could ensure continued economic success even after state and federal tax credits expire.

As Edgar DeMeo, manager of EPRI's Solar Power Systems Program, points out, "The tax credits have been critical in attracting investment capital to the fledgling small power producers' field. Although they have resulted in the installation of wind turbines that would not otherwise be economical, they have allowed engineering development to be conducted in the field with statistically significant numbers of machines.

"To achieve credibility as a viable business option over the long term without tax credit subsidies, some of these machines will have to demonstrate reliable operation over significant periods with acceptable O&M costs. We feel this is indeed possible," DeMeo adds.

Concurrent with manufacturers' efforts to improve the reliability of today's small wind turbines, several vendors have constructed machines in the 200–400-kW range. These turbines have been built in limited numbers and significant experience is just beginning to accrue, but a definite industry trend is seen toward higher generator ratings.

Large wind turbines

Several megawatt-scale turbines are in operation today, producing energy as well as valuable data on their long-term performance and economics. Generally, these machines are the product of aerospace technology, combining state-of-the-art understanding of helicopter rotor design, structural dynamics, and hydraulic rotor-pitch controls.

The premier development effort in large wind turbines has been carried out by NASA, Lewis Research Center under sponsorship of the Department of Energy (DOE). The DOE–NASA program, begun under other agencies in the early 1970s, has involved development by several contractors of a series of progressively larger wind turbines, leading to the current-generation MOD-2, a 2.5-MW, 300-ft-rotor (91-m) design built by Boeing Co.

Three MOD-2s were placed in operation at Goodnoe Hills, near Goldendale, Washington, in 1981 for evaluation on the Bonneville Power Administration network; a fourth unit is at the Medicine Bow, Wyoming, site of a U.S. Bureau of Reclamation project to evaluate wind energy integration with hydroelectric power from the Colorado River Storage Project.

Pacific Gas and Electric Co. is testing a fifth MOD-2 turbine at a site in Solano County, California, northeast of San Francisco. As of February 1, 1984, PG&E's MOD-2 had accumulated over 1500 h of rotation and generated over 2100 MWh.

Design and construction of the MOD-2 turbines was one of the more notable success stories of the federal government's solar energy programs in the late 1970s. But problems that have surfaced with the MOD-2s may have important implications for the future of large wind turbines.

After about seven months of operation, the first of the Goodnoe Hills MOD-2s suffered a damaging overspeed event in June 1981 that resulted from a hydraulic valve failure during a test of the emergency shutdown system. The unit's generator and other components were badly damaged, placing the turbine on the disabled list for nearly nine months and requiring modifications to the other MOD-2s at the site.

About 18 months later, the same unit shut itself down during another test; this time, technicians found a large crack running two-thirds of the way around the thick, low-speed steel shaft that supported the 100-t rotor. All other MOD-2s were idled for the next 7 months while engineers studied the problem. The 15-ft (5-m) drive shafts on all three Goodnoe Hills MOD-2s were replaced with new, sturdier designs, keeping the units down for most of 1983. Major modifications, including the addition of a crack detection system, were required on the MOD-2s in Wyoming and in California.

Problems such as those that have occurred with the MOD-2s are not unexpected in any large technology R&D program, but the implications fuel concerns that so much complexity and cost have been built into large wind turbines that they may be further from commercial availability than once believed by some enthusiasts. Delayed development of the next generation of large wind turbines and the withdrawal of two major potential turbine suppliers from the field contribute to the growing perception that large, megawatt-scale wind turbines may not be optimal for most commercial applications in the foreseeable future.

The MOD-2s are considered second-generation large wind turbines, incorporating experience from earlier prototypes. Their design aimed at generating low-cost energy with turbines produced in large numbers. In today's market for wind turbines and the current utility economic environment, however, such production levels are not justified. Never intended as mature commercial wind turbines, the MOD-2s were viewed within the federal R&D program as the steppingstone to a more advanced turbine that could generate energy at an even lower cost. This third-generation turbine, called the MOD-5, has not yet been built.

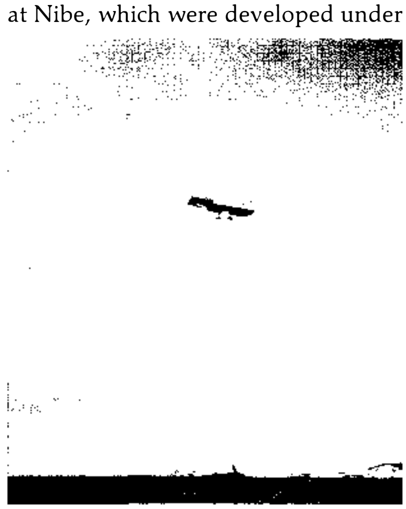
Two design concepts of the MOD-5 were considered: a 7.3-MW, 400-ft-

Canada and several European countries maintain substantial wind turbine development programs; nearly all are coordinated, cooperative efforts of government agencies, industrial manufacturers, universities, and utility organizations. Canada's R&D program has focused mainly on vertical-axis machines. The many experimental turbine designs deployed to date in Europe are broadly characterized by generous structural safety margins with correspondingly less attention to minimizing capital costs. Blade designs have focused on the use of lightweight fiberglass materials.

Sweden's and West Germany's wind programs, emphasizing megawatt-scale horizontal-axis designs, have produced operating turbines now considered the state of the art for European wind machines. Sweden's program is marked by much greater utility organization involvement than is West Germany's. Vattenfall, the Swedish State Power Board, is operating the 2-MW KaMeWa turbine, which features a concrete tower and a unique drivetrain design, on Gotland Island. Sydkraft, the country's second largest utility, is testing the 3-MW WTS-3 turbine at Maglarp. Rotor blades for this machine were supplied by Hamilton Standard in the United States.

The Growian I and Growian II machines in the Federal Republic of Germany were built by industrial firms for the Kernforschungsanlage Julich (KFA), which manages the German wind program. The Growian I, a 3-MW, 100-m-rotor (330-ft) machine near Brunsbuttel, boasts the world's largest-diameter rotor and features a variable-speed generator. Growian II, near Bremerhaven, boasts the world's largest single-blade turbine.

Denmark, once Europe's frontrunner in turbine technology, has shifted its emphasis to smaller designs, compared with Sweden's and Germany's megawatt-scale machines. Riso National Laboratory at Roskilde manages a government test and certification program for turbines in the 50-kW range. Several hundred such machines are operating throughout Denmark; within the last year, larger models of Danish designs have also been installed in some California wind developments. The Danish utility Elsam is operating two 630-kW wind turbines at Nibe, which were developed under the management of the Technical University of Denmark.


WTS-3 in Sweden

Further behind its neighbors on the continent, the United Kingdom plans a multiturbine development on the isolated Orkney Island power system as a major step in developing wind resources. An industrial group of aerospace, energy, and construction firms has already placed in operation a 250-kW, 20-m-rotor (66-ft) turbine on Orkney, with a 3-MW, 60-m (20-ft) design scheduled for completion in 1985. Future plans call for two other large turbines at the site.

Canada's National Research Council directs a broad-based effort to develop vertical-axis turbines in a number of sizes. A 230-kW machine is operating at a site in the Magdalen Islands in the Gulf of the St. Lawrence River. The government, industrial firms, and Hydro-Quebec are jointly developing a multimegawatt vertical-axis machine. An Ontario-based manufacturer, DAF Indal, has supplied several vertical-design turbines, including a 50-kW model for the California Department of Water Resources at San Luis Reservoir and a 500-kW scaled-up design for SCE.

Other nations have significant, but more-modest and less-advanced, wind energy programs, including France, Italy, the Netherlands, Norway, Japan, Australia, and Brazil. Observers note that the Dutch effort in small-turbine R&D has begun to accelerate in recent months. □

rotor (122-m) MOD-5A, to be designed by General Electric Co.; and a 7.2-MW, 420-ft-rotor (128-m) MOD-5B, to be designed by Boeing. The MOD-5B was later downsized to 3.2 MW, and the rotor reduced to 320 ft (98 m)—slightly longer than a MOD-2 rotor. Under a plan adopted by DOE–NASA in 1980, each contractor was to have one MOD-5 turbine ready for testing in 1984.

Both designs were to incorporate existing concepts employed in the MOD-2, as well as insights gained in operating the second-generation machines, such as the effects of structural loading on the fatigue life of major components. Shutdown of the MOD-2s during much of the MOD-5 design period, however, prevented some important feedback. The MOD-5s were also to feature significant design innovations, such as variable-speed generation, intended to lower the cost of energy from MOD-2 projections and reduce structural loading.

As often happens with technology R&D, however, politics and economics worked to alter the outlook for continued development of large turbines. First, a new administration took charge in Washington, D.C., with a markedly different philosophy regarding the role of the federal government in the energy marketplace; DOE's wind energy budget in 1983 dropped from a level of about $60 million the previous year to less than $20 million. As a result, the MOD-5 development effort was transformed from a government demonstration project to a cost-sharing arrangement with the turbine suppliers, potential host utilities, and EPRI.

Second, world oil prices—a fundamental incentive to exploit wind—began to fall around the turn of the decade, eroding the perceived urgency for wind technology deployment.

Finally, General Electric, citing these reasons as well as forecasts of reduced utility load growth and the uncertain extension of federal wind energy tax credits, withdrew late last year from a contract with Hawaiian Electric Co. to demonstrate the MOD-5A on Oahu's Kahuku Point. General Electric said it had unsuccessfully sought to interest dozens of other utilities and small power producers in purchasing MOD-5s and therefore concluded there was no present or near-term market for the turbine. Discussions continue, meantime, between DOE–NASA, Boeing, and potential utility participants regarding development of the MOD-5B turbine.

Other firms have pulled back from the large wind turbine business as well. Bendix Corp. and Aluminum Co. of America, both of which fielded experimental machines, have withdrawn from the wind business. And Hamilton Standard Division of United Technologies Corp. has indicated it is no longer seeking buyers for commercial models of its WTS-4 turbine. The 4-MW machine, designed for high reliability and fatigue life, is considered an impressive engineering achievement; significant further evaluation and development are required before its commercial prospects can be known with confidence, however. One prototype is operating near a MOD-2 machine at the USBR Medicine Bow site.

Meantime, Westinghouse Electric Corp., builder of the four 200-kW MOD-0A experimental turbines—one of the early DOE–NASA first-generation designs—is developing a 500-kW machine as a commercial product for the current subsidized wind turbine market. Through refinements anticipated in coming years, Westinghouse hopes a turbine will evolve that will remain commercially viable beyond current subsidies.

Clearly, recent events in the large wind turbine field have been disappointing. This is not to say these machines have no future, however; it may simply be further off than once believed.

As Louis Divone, director of solar electric energy technologies at DOE, explains, "From the beginning of the large turbine portion of the federal wind program, we knew that if we made them too small the energy would be too expensive, so as they get bigger the economics gets better. But as you go to features like microprocessors and automatic controls, active yaw control, and advanced airfoils, you have to make the systems large enough to pay for the complexity. Eventually, the square-cube law gets you, where the power is going up by the square of the rotor diameter and the mass is going by the cube, and somewhere on the scale, the cost of energy produced starts to skyrocket.

"We always knew you could build a large wind turbine stout enough to last whether you understood the structural fatigue loading or not," Divone adds, "but the costs go up because you're paying for a lot of steel. As you design for greater cost-effectiveness, how close can you cut the margins? The closer you cut them, the more you have to know about the structural loading input, and in the case of a wind turbine, that's rather complex."

The technology of large turbines awaits technical advances and shifts in economic forces before significant numbers are built or installed. Until then, current test and evaluation programs on existing large turbines are essential not only to enhance the substantial technical base developed over the years but also to gain the insights that can lead to improved, smaller turbines.

Wind farms sprouting

While economic forces have delayed the commercial viability of large turbines, politically mandated intercession with those forces has triggered the birth of the small wind turbine field. Thousands of small turbines have sprouted to take advantage of state and federal renewable energy tax credits. An EPRI-sponsored 1983 survey of wind power producers found over 100 active companies and describes 85 operating wind power stations. Turbines installed as of July 1983 have an estimated aggregate generator rating of some 80 MW, with an additional 650 MW planned through this year.

In California, home to most of the

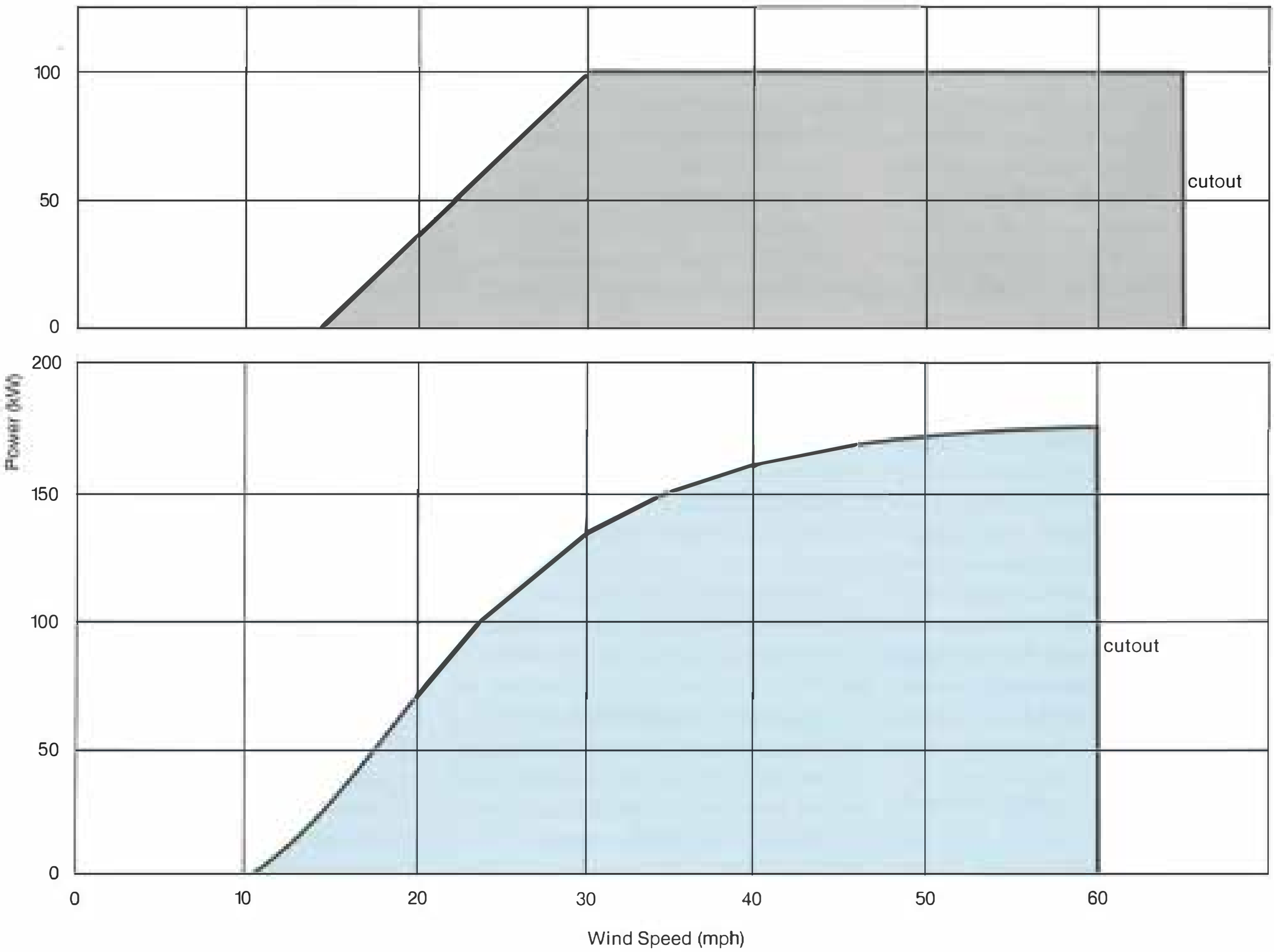
wind turbines, an estimated 500 MW will be on line by the end of 1984, according to the state energy commission. Analysts attribute the current concentration of wind developments in California to a number of factors: avoided-cost rates paid by utilities are slightly higher than the national average because the state generates most of its electricity with oil-burning power plants; combined state and federal tax incentives are unusually attractive; the state has several areas that are considered to have good wind resources; and a large part of the population is sufficiently affluent to take advantage of investment opportunities in wind power.

Most California wind ventures to date have been in one of three main areas: the Altamont Pass area east of San Francisco; the San Gorgonio Pass east of Los Angeles, near Palm Springs; and the Tehachapi Mountain range north of Los Angeles in Kern County.

Three of the state's major utilities—PG&E, Southern California Edison Co., and San Diego Gas & Electric Co.—are gaining experience integrating wind energy from independent producers with their transmission and distribution systems. In addition, PG&E and SCE are both engaged in wind turbine testing programs—PG&E with its MOD-2 near the Carquinez Straits northeast of San Francisco, and SCE with four different machines at San Gorgonio Pass, including a 500-kW vertical-axis eggbeater-type turbine made by DAF Indal Ltd. of Canada.

Wind turbines with the same rated power output may produce significantly different amounts of energy under identical wind conditions, depending on the operating characteristics that are unique to specific designs. Thus, a given turbine may generate more kilowatthours than a machine of higher rated power at the same site. Some turbines achieve full rated output in relatively low winds, and maintain full power until cutout speed is reached; other machines show a more gradually sloping power curve in which rated power is not reached until wind speed is much closer to cutout speed. Verifying a turbine's actual power curve is the key to estimating energy production.

Sample Wind Turbine Power Curves



EPRI'S WIND RESEARCH

A key objective of EPRI's wind R&D is to understand, analyze, and interpret for the utility industry the rapidly evolving trends in wind power development. EPRI's involvement can help advance the technology as a viable utility power generation option.

Through data- and cost-sharing agreements with several utilities, the federal government, and private developers, EPRI is monitoring the operating experience of all sizes and major designs of wind turbines. These include the three MOD-2 turbines at Goodnoe Hills, PG&E's MOD-2, Hamilton Standard's WTS-4 machine, and fifty 50-kW wind turbines operated by a private developer at Altamont Pass.

EPRI is also gathering operating data on three sizes of vertical-axis wind turbines, popularly known for their eggbeater appearance. Two of the machines—one rated at 50 kW and a scaled-up 500-kW model—are manufactured by DAF Indal and operated by SCE at San Gorgonio Pass.

More-extensive analysis of wind turbine performance is being conducted on selected machines. Key attributes, which must be carefully evaluated over significant periods of operation, in developing a reliable, technically sound wind turbine include structural, aerodynamic, mechanical, electrical, and control characteristics. Understanding these factors is essential to advanced turbine design.

A key research need relating to advanced design is more-accurate measurement and characterization of the wind passing through the area swept by a turbine rotor. Existing measurement techniques and devices are of little help in defining the complex interaction of wind, rotor, and terrain.

An innovative approach tested by Battelle, Pacific Northwest Laboratories under EPRI contract employs hot-film anemometers mounted along the rotor span that permit rotational sampling of the winds on an operating turbine. Early tests of this approach were performed on a MOD-2 machine. Data from such measurements could lead to improved rotor aerodynamic design and a better understanding of structural loading.

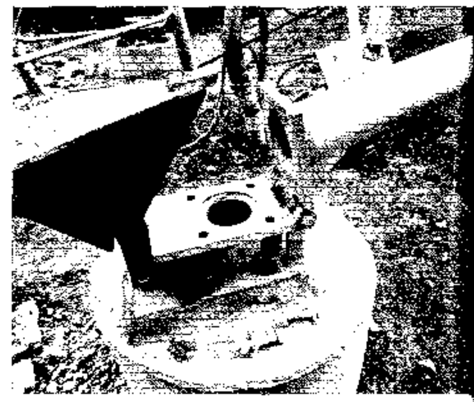
EPRI has also sponsored projects to help utilities assess the economic and operational aspects of wind power. These include estimates of wind turbine and balance-of-station costs, studies of the dynamic impact of wind energy on utility systems, cost-value studies of different levels of wind power penetration in specific utility systems, and simulation models for predicting operational impact.

As more utilities consider wind power development in their territories, the need grows for improved methods for wind resource assessment and turbine siting. The many reports, maps, and atlases produced in the federal program to characterize wind resources in the United States provide a good starting point for utilities siting wind turbines.

Building on this work, EPRI has developed a methodology for siting single or clustered wind turbines. It provides a systematic procedure for site identification that allows users to identify and screen candidate sites without extensive on-site instrumentation and analysis.

Verifying that a candidate site indeed has good wind characteristics, however, does require extensive measurement and analysis. Results from current turbine evaluation programs highlight the need for more detailed knowledge of the effects of turbulent eddies, wakes, and wind shear on the fatigue life and energy output of a wind turbine. □

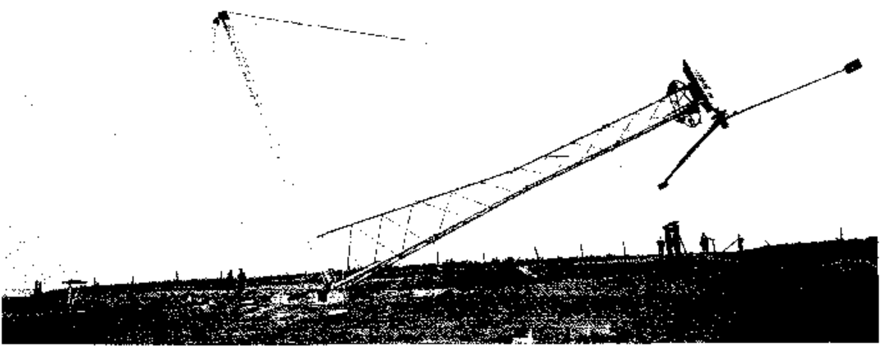
A key to minimizing operation and maintenance costs of wind turbines involves design for easy installation and service access. Numerous construction techniques are employed in turbine installations, including the use of expensive crane rigs (far right). One of the simplest approaches is demonstrated with a wind turbine manufactured by ESI, Inc. Using lifting cables and a winch, the machine can be raised and lowered on a hinged foundation mount. The turbine in the photographs was installed in the Altamont Pass region of California.

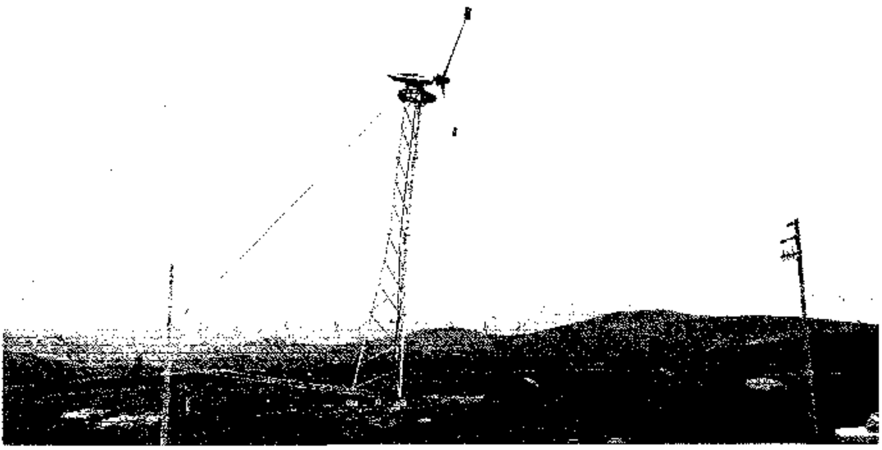


A critical factor in spurring wind turbine installations has been the presence of highly attractive federal and state tax credits for solar energy investment. In some cases, these incentives can recover for investors as much as 40% of a project's cost in the first year of operation. Rapid depreciation of capital costs under the Energy Recovery Tax Act adds to wind energy's investment appeal.

"The tax incentives are providing a window, a period of time when a lot of small turbines are being deployed," explains John Cummings, director of EPRI's Renewable Resources Systems Department. "The bulk of the limited partnership tax advantages accrue in the first three years. The important question is how many of the developers will be around after the tax advantages expire." The 15% federal solar energy tax credit is slated to expire in 1985, and the outlook for congressional extension is uncertain. California's 25% energy tax credit has been extended through 1986.

"Among small turbines there are some sophisticated machines that show poten-





tial availability exceeding 90%. On the other hand, there are some poorly designed machines, many of which have already failed. It's the machines on the lower end of reliability that won't survive on their own without tax credits. Some developers are trying to engineer better machines. They're making them larger, and the reliability and availability are getting better. Some developers now even offer warranties on machine availability and energy production.

"If the reliability of today's turbines can be improved and if the machines can be made larger," adds Cummings, "we can see an economically viable, sustained business in wind quite independent of the tax credits."

As Cummings points out, larger, more-reliable machines could mean the difference between profit and loss for many wind developers after tax credits expire. Already, some turbine manufacturers are scaling up their designs for greater energy capture from the wind and, in turn, more revenue per turbine. In the Altamont Pass area, some fifty 200-kW machines and ten 400-kW turbines that are essentially scaled-up versions of earlier, smaller designs have been installed.

"Clearly, we want to get to larger machines," says Cummings. "But how much bigger can they get and still have good reliability without the complexity, cost, and risk of a large wind turbine? We don't know what the optimal size is.

"The federal government has done most of the work on large machines, and small industrial organizations have developed most of the small machines. But the technology that is needed to develop a 400- or 500-kW machine may turn out to be beyond the talents of the small turbine manufacturer. There may be a need for an organization that can have several contractors systematically working on the problem."

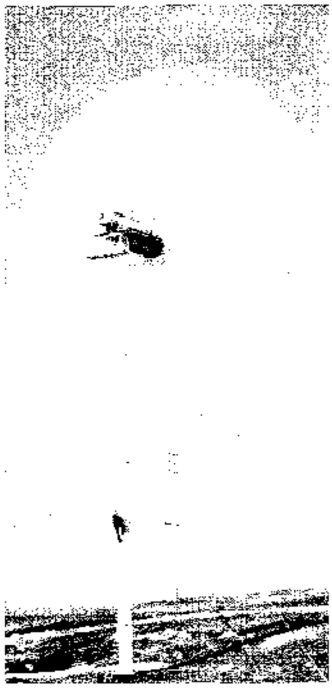
EPRI is currently considering alternative approaches to enhancing wind turbine development efforts. The dilemma for the wind turbine community is how best to apply limited R&D resources to a task that can consume funds all too quickly, as the federal experience has shown. "It appears as if we might be most effective by looking into building a 400–600-kW machine," comments Cummings. "But how do we apply insight from the present base of operating experience with all sizes of machines to scale up the small ones? We don't know the answer yet."

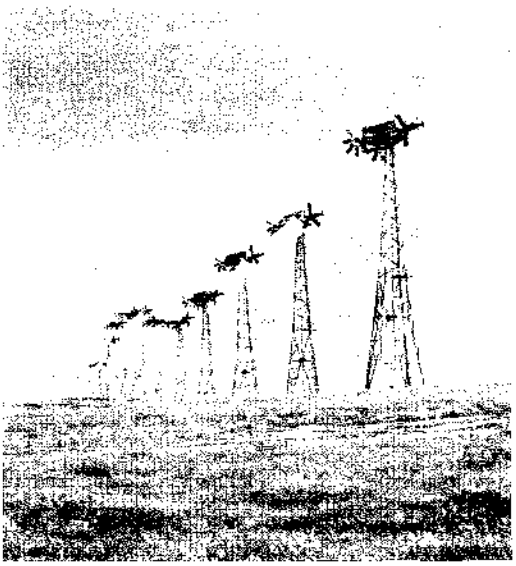
Adds Goodman, "The key is to strike the proper balance between turbine complexity and turbine size. The research path for the next few years should start with state-of-the-art machines of about 200 kW, scale them up while retaining design simplicity, and then selectively evaluate the merits of individual technical innovations. Experience with machines of all sizes will provide important input in identifying appropriate refinements. Only those features that enhance overall economics should be retained in commercial machines."

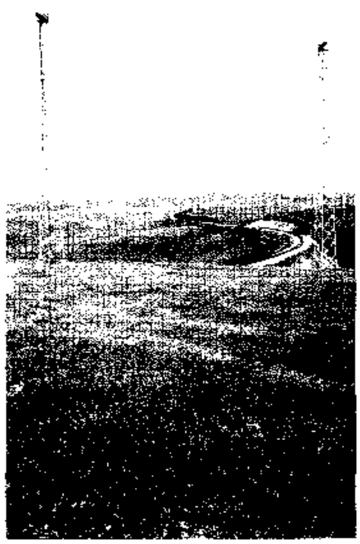
A future for wind

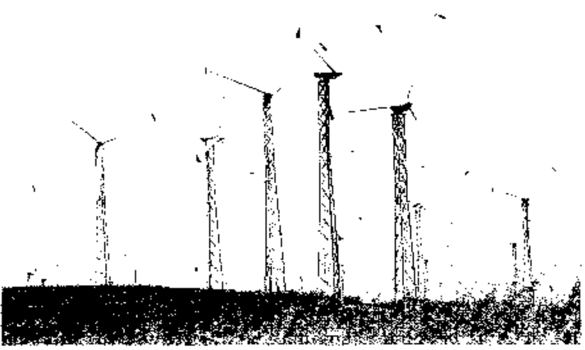
Regardless of the size or design of the wind machine that eventually emerges from government and private R&D ef-

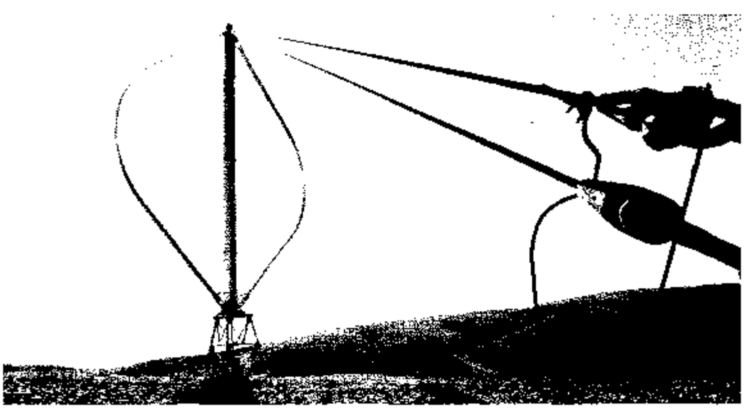
The Altamont Pass region east of San Francisco Bay boasts of more installed wind turbines than any other wind resource area in the country. Six small power producers now sell electricity to Pacific Gas and Electric Co. from more than 2000 wind turbines operating at Altamont Pass. The northern California utility reports that in 1983 it purchased a record 31 million kWh from wind turbine owners.











forts as the best suited for commercial development in utility applications, wind power's ultimate contribution to the nation's energy needs will strongly depend on maintaining the momentum achieved over the last decade. Although in many parts of the country wind is generating valuable energy as well as experience, the technology is still in the R&D phase. Despite mechanical problems with some wind turbines and other disappointments, there remains much cause for optimism.

Now, in the 1980s, a lessened sense of urgency is apparent in much of the R&D effort on renewable energy technologies. This may be fortuitous in that it provides a breathing period to reassess the progress and problems with such technologies as wind so that they are fully understood when truly needed. "No question, we will get to the point where the energy-economic pendulum will swing back again," notes Cummings. "So it's very important to position ourselves with new technologies during this lull. We think wind is going to be one of them. Now is the opportunity to demonstrate the technology so it will be there when the economics again look right and we find ourselves in another energy crisis."

Further reading

Wind Turbine Performance Assessment, Technology Status Report No. 7. Final Report for RP1996-1, prepared by Arthur D. Little, Inc., April 1984. EPRI AP-3447.

Early Utility Experience With Wind Power Generation. Final Report for RP1590-1, prepared by JBF Scientific Corp., January 1984. Vols. 1, 2, and 3. EPRI AP-3233.

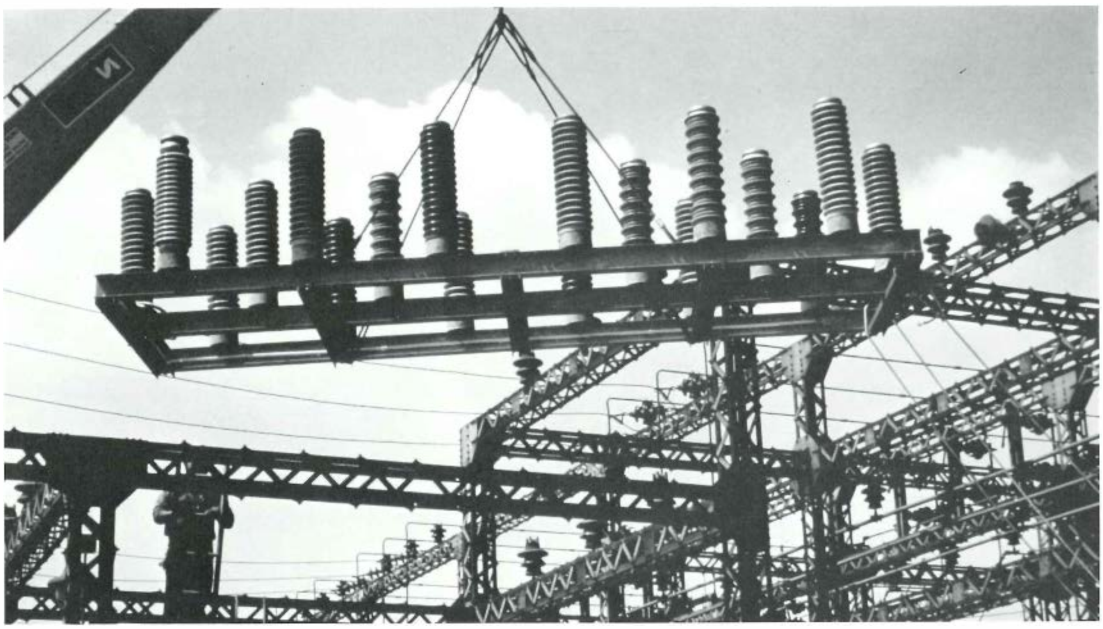
Wind Power Parks: 1983 Survey. Final Report for RP1348-17, prepared by Strategies Unlimited. In press. EPRI AP-3578.

Methods for Wind Turbine Dynamic Analysis. Final Report for RP1977-1, prepared by Systems Control, Inc., October 1983. EPRI AP-3259.

"Wind: Prototypes on the Landscape," *EPRI Journal*, Vol. 6, No. 10 (December 1981), pp. 26–34.

This article was written by Taylor Moore. Technical background information was provided by Frank Goodman, Jr.; Edgar DeMeo; and John Cummings; Advanced Power Systems Division.

Polysil Poised for the Marketplace



After three years of field tests, Polysil* insulators are still performing well and fulfilling expectations for a superior insulating material.

Once in a great while a material is developed whose characteristics are so unusual and so promising that it is best characterized as a substance in search of an application. Polysil, a polymer concrete developed by EPRI as an electrical insulator, shows every indication of being such a material. In fact, it has found not only an excellent application but a commercial market as well.

Polymer concretes were first developed in the United States in the mid 1960s by the Bureau of Reclamation and Brookhaven National Laboratory under the sponsorship of the Atomic Energy Commission. Early testing of the material indicated that it had extraordinary physical properties that pointed to many opportunities for practical use. As a construction

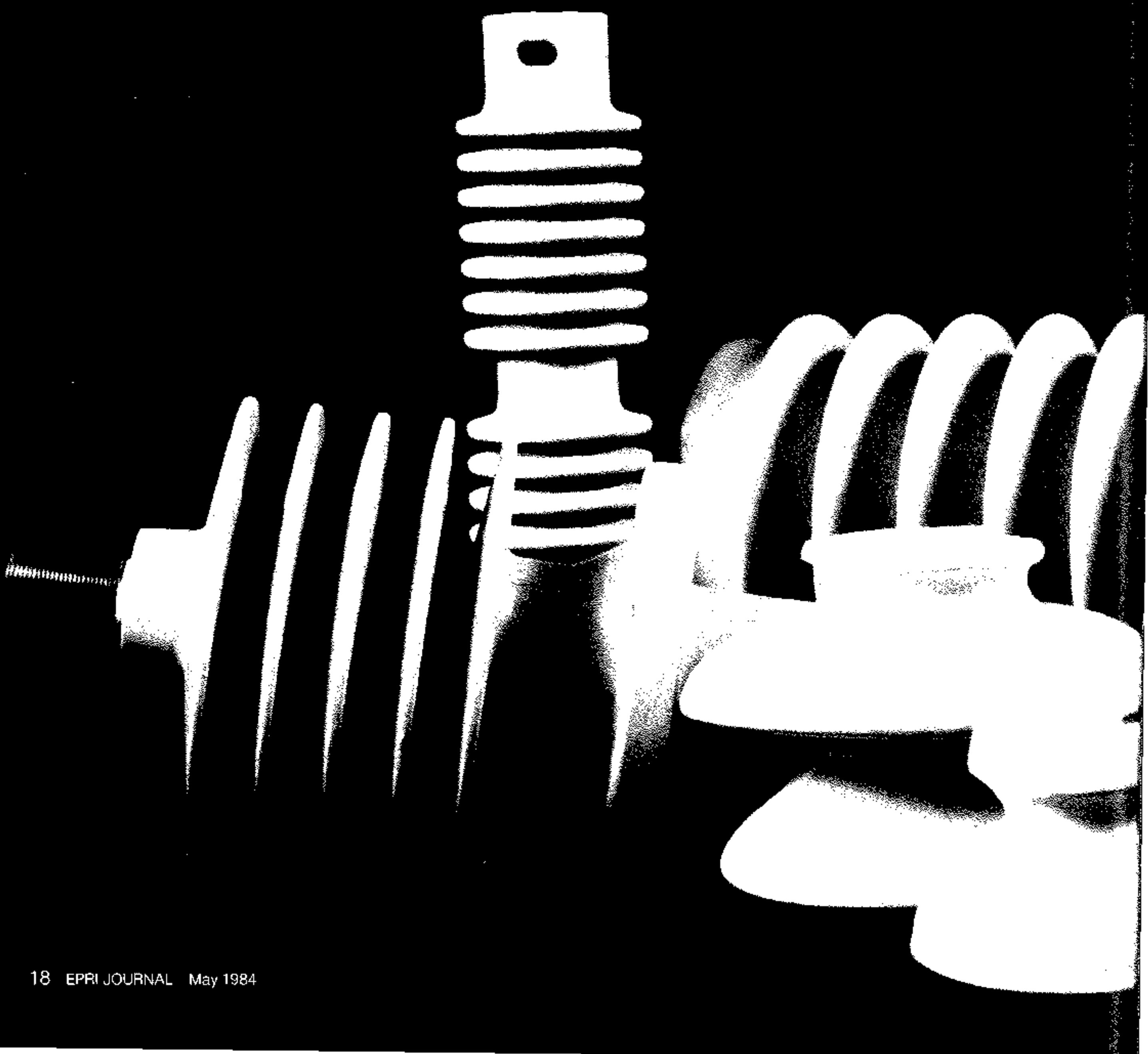
*Polysil is an EPRI trademark.

material in spillways and stilling basins of dams, for example, the polymer concrete resisted erosion exceedingly well; in harsh environments, such as desalination plants, it showed remarkable corrosion resistance. With six times the compression strength of conventional concrete, the polymer concrete also bonded well with a variety of road construction materials.

Applications for the new material were first pursued in the defense industry for everything from a replacement for concrete to armor plating. Dust-free and impervious to acid and alkali, polymer concrete even proved to be an excellent, though relatively expensive, flooring material.

The possible electrical application of polymer concrete was recognized by EPRI, and in 1975 Westinghouse Electric Corp. was chosen to investigate this potential in an 18-month, $275,000 study. After further development and testing, a new insulating material appeared that was suitable for outdoor applications. It was simple in composition—about 90% silica in various sizes for maximum packing, bound together by a resin in monomer form that polymerized after mixing. EPRI called the material Polysil and patented the formula.

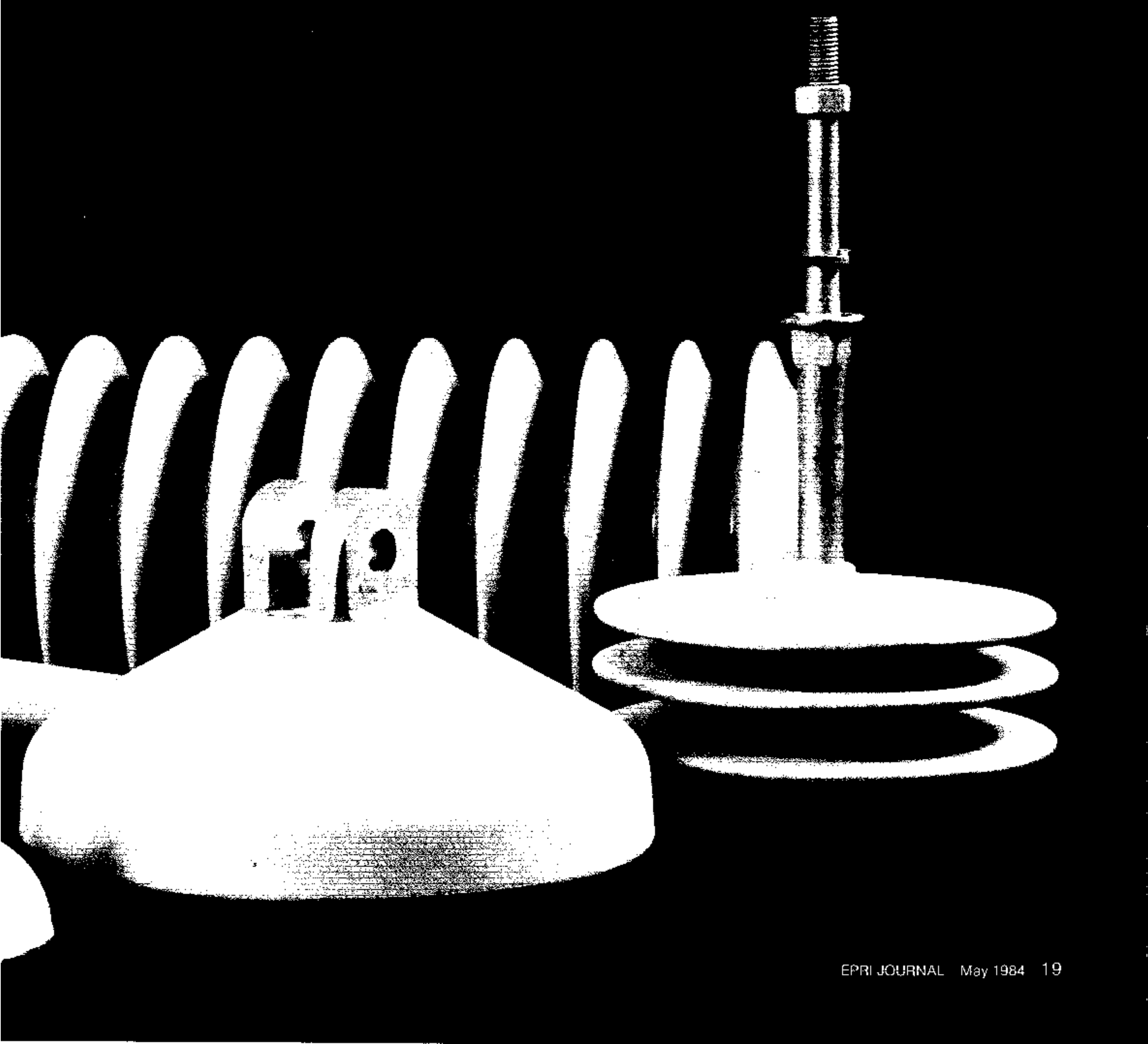
In 1983 a Polysil licensee was awarded



a coveted IR-100 Award by *Industrial Research & Development* magazine. From a field of over 10,000 materials and processes, Polysil was chosen as one of the 100 most significant technical products of the year—a potential replacement for porcelain, epoxy, and glass in the manufacture of insulators. EPRI Project Manager John Dunlap adds that Polysil has been licensed by more manufacturers than any other EPRI product. "Several overhead line insulators are now offered for sale, and new products are making their way to the marketplace monthly. Polysil is a great example of a good idea carried through to the commercial stage."

Polysil as product

Polysil's advantages over conventional insulator materials derive from the product itself and also from how its properties affect the manufacturing process. Polysil has excellent mechanical and dielectric strengths, and because of its formula, it is nontracking—its surface will not carbonize even under severe arcing. It polymerizes without heat and can be cast into detailed shapes. In addition, Polysil's processing allows the encapsulation of such metal components as voltage grading end caps, resistors, capacitors, and mechanical attachments. This feature, in turn, allows new flexibility of insulator design



MANUFACTURERS OF POLYSIL INSULATORS

Lindsey Manufacturing Co.
760 N. Georgia Ave.
Azusa, California 91702
(213) 969-3471

Polytech Co.
118 Willow St.
Redwood City, California 94063
(415) 369-7363

Syntechnics, Inc.*
2775 Channel Ave.
Port of Memphis, Tennessee 38113
(901) 775-2444

OTHER POLYSIL LICENSEES

Atlas Minerals & Chemicals, Inc.
Farmington Road
Merztown, Pennsylvania 19539
(215) 682-7171

Canterbury Engineering Co., Ltd.
P.O. Box 9045
Christchurch 2, New Zealand

Electrical Equipment Co.
P.O. Box 9929
Birmingham, Alabama 35215
(205) 853-1443

Polymar Products
P.O. Box 384
Valley City, North Dakota 58072

Reynolds & Taylor
2109 South Wright St.
Santa Ana, California 92705
(714) 540-4850

Tolley Holdings
Central Chambers
P.O. Box 665
Wellington, New Zealand

*Syntechnics will offer Polysil insulators later in 1984.

and manufacture.

Savings are inherent in Polysil's manufacture. Because kiln firing is not part of this process, immediate savings of money, time, and fuel are possible. In the long range, Polysil's cost will be largely independent of the future costs of fuels used to power the kilns necessary for porcelain production. Because nobody has yet begun the operation of a highly automated production facility, the full potential cost savings have not been determined. However, in light of Polysil products already on the market, there is reason to believe substantial reduction in insulator costs can be achieved. The available Polysil products also indicate some of the design flexibility possible.

Post-type insulators were the first products to be developed from the new material. Today, even without volume production facilities, a 69-kV insulator made of Polysil sells for about $90–$100, as opposed to $150–$160 for its porcelain counterpart. Smaller insulators in the 15–35-kV range are also available and, according to their manufacturer, "perform as well as, or better than, porcelain insulators while offering economic savings." Automated production facilities will bring down the costs further. In addition, tests have shown that the Polysil design, with its voltage grading features, has higher flashover voltage than conventional insulators.

The Polysil hook-stick switch is a good example of the more efficient, more economical design made possible by the material's electrical and mechanical properties. Previous design for porcelain switches necessarily consisted of many parts—the metal base, the insulators, switch parts, and the switch blade itself. Now, with Polysil, the base and insulators can be cast in a single unit and the switch blade mounted onto an insert cast into the top of the insulator. The simplified design leads to a reduced manufacturing cost and a lower cost to the utility.

Shed well bushings also offer an opportunity for Polysil to show off its advantages. The energized rod through the center of the shed well bushing makes tight tolerances essential. With porcelain, these dimensions are difficult to obtain, but Polysil's casting process allows for very tight tolerances. The rod is cast with the insulator, and as the Polysil cures, it shrinks slightly to a tight, void-free interface. In use, the Polysil insulating material has a thermal expansion coefficient very close to that of the embedded copper, and it contracts and expands with the metal. A line of these bushings in the 15–35-kV range is available.

The only real uncertainty for Polysil at this point is its long-term performance in actual service. Manufacturers and utilities have been waiting for the answers to the initial questions of Polysil's durability and longevity, questions that only can be answered with field testing.

Field tests

EPRI began comprehensive field testing of Polysil insulators in 1980. The test involves racks containing 17 Polysil 69-kV post-type insulators of various designs and one porcelain insulator as a control. The racks are distributed at 25 sites throughout the United States and Mexico, from Vancouver to Tapachula. This distribution was designed to ensure as broad a range of environments as possible—arid and humid, hot and cold, urban and rural, clean and contaminated. Overall, two styles of skirt design, two Polysil formulations, three types of internal voltage gradings, and four types of external coatings are being tested. The racks are fully instrumented to measure various types of surface leakage currents, which will be correlated with atmospheric conditions.

At this point, all but one of the stations have been energized and have endured at least one complete weather cycle. Over three years of exposure, most of the Polysil field test racks are holding up as well as developers had hoped. The simplest design—no grading components and no coatings—is performing the best, but none of the insulators have experienced a failure.

Commercialization

Currently, EPRI has licensed nine manufacturers, several of whom are already introducing products in the United States. Two New Zealand companies have a license, and companies in Japan, Nigeria, and England have expressed interest. Each licensee is expected to fulfill these basic requisites: a background in the technology, facilities available for production, financial stability, and a commitment to commercialization and quality control.

Although none of the licensees have yet embarked on commercial manufacturing on the same scale as porcelain insulator manufacture, domestic Polysil products, including post-type insulators and the hook-stick switch, have found markets as far-flung as Australia and Norway. Recently, one manufacturer began offering Polysil repairs for porcelain bushings and insulators. Polysil's extraordinary bonding properties and molding flexibility make previously impossible repairs a matter of one day's work in many cases.

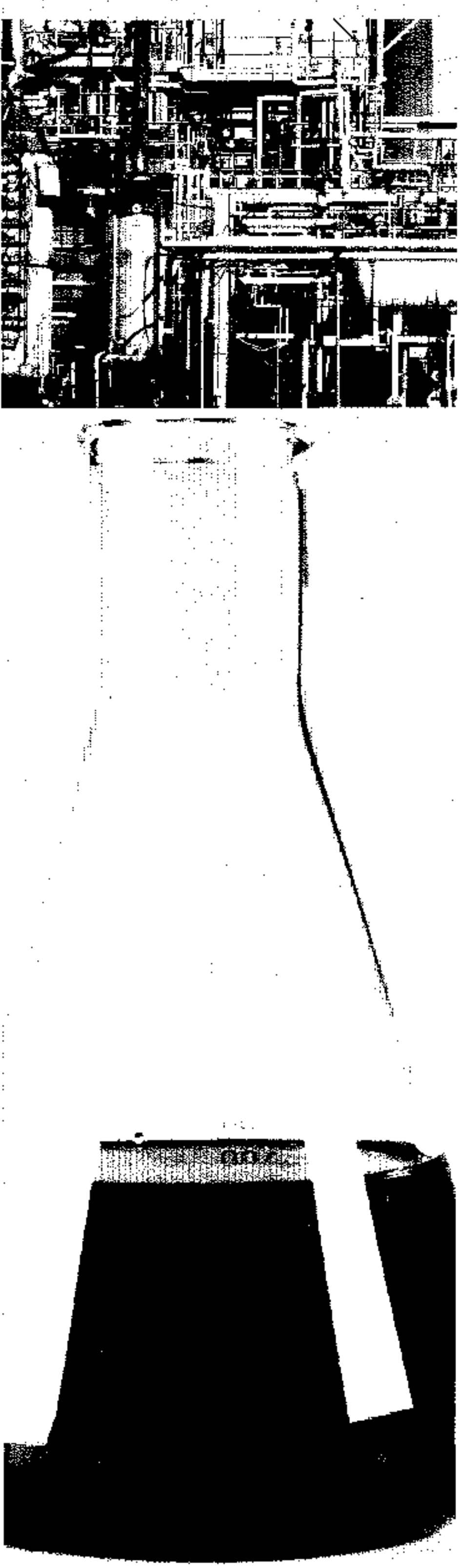
Several manufacturers are expanding their facilities for Polysil insulator production this year. Future commercialization may see Polysil move beyond the niche now occupied by porcelain. Because it is a structural as well as an insulating material, Polysil may eliminate the need for separate insulators in substations. Instead, the entire structure would act as an insulator, leading to a more compact, esthetic, and economical design. Utility pole crossarms might also be combined with the insulators into one insulating and structural unit.

The bottom line good news for the utilities is that after six years of research, development, and testing, Polysil has made good on its early promise. It has proved to be an excellent insulating material with superior dielectric and mechanical strength, resistant to tracking, flexible in both design and production, and, now, field-tested for durability and longevity in a wide spectrum of environments. In 1978 the *EPRI Journal* noted that "when a new material appears on the scene that does more, does it better, and costs less than existing materials, it can truly be called a breakthrough." With three years of field tests behind it, Polysil matches that definition even better now than it did then. ■

This article was written by Stephen Tracy, science writer. Technical background information was provided by John Dunlap, Electrical Systems Division.

Narrowing the Field in Coal Liquefaction

The Advanced Coal Liquefaction R&D Facility at Wilsonville, Alabama, is the largest plant still dedicated to liquefaction research. The two-stage process developed there remains a strong candidate for scale-up when oil economies again shift.



Converting coal from a heterogeneous, combustible solid to a clean, liquid fuel that would rival oil in utility and flexibility has been a dream of chemists since the early part of this century. In 1913 the German chemist Friedrich Bergius discovered that treating coal with hydrogen at high temperature and pressure in the presence of a catalyst produced an oil similar to crude petroleum. Industrial development of the Bergius process in Germany in the 1930s and 1940s helped fuel the Nazi war machine with coal liquids during World War II.

Political intent notwithstanding, the basic motivation of interest in coal liquefaction today remains the same. With abundant indigenous coal resources and the technologic capability to liquefy the coal on an industrial scale, a nation dependent on oil for primary energy would feel less threatened by the seemingly inescapable potential for political disruptions in supply or economic disasters in price that are associated with oil. The appeal of substituting liquid coal produced from within our own shores for oil shipped here from an unstable part of the world is readily apparent.

With the oil price shocks of the 1970s and the realization that those shocks were only the beginning came a strong resurgence in coal liquefaction R&D in the United States, as well as in other oil-dependent Western nations. Over the decade, liquefaction processes that amounted to technical variations on a basic theme proliferated and competed for both private and public capital in a race to be first with a technique that promised commercial-scale production at a cost competitive with the ballooning price of oil. Two basic approaches that emerged from this competition—the H-Coal and Exxon Donor Solvent (EDS) processes—were developed through the pilot plant stage early in the 1980s.

But in the last few years, oil economics have again worked to change the pace of coal liquefaction development. Cartel pricing triggered significant conservation, which, in turn, gained momentum of its own; serious economic recession in the West further dampened demand both for oil and for alternative substitutes; a decade-long legacy of inflation widened the gap between the cost of producing coal liquids and that of oil on the open market. In addition, a new administration in Washington, D.C., took charge and was determined to shift much of the federal government's role and fiscal burden in energy research to the private sector.

As a result of these and other factors, the coal liquefaction demonstration and commercial production plants envisioned in the 1970s never made it from the drawing boards to the construction stages. Development of the industry remains stalled at the level of the large (250 t/d) H-Coal and EDS pilot plants, whose work is now complete. A few new liquefaction processes, however, continue to be developed at a smaller scale and are strong candidates for scale-up once the economic winds again shift.

One of the more technically and economically promising liquefaction processes to emerge from the flurry of R&D effort is two-stage liquefaction (TSL), a technique in which EPRI has had a continuing commitment since 1975. TSL is being developed at the Advanced Coal Liquefaction R&D Facility under cosponsorship of EPRI and the Department of Energy.

"TSL is a step beyond H-Coal and EDS," says Howard Lebowitz, manager of the Clean Liquid and Solid Fuels Program in EPRI's Advanced Power Systems Division. "H-Coal and EDS have been well demonstrated in large pilot plants whose work is now finished. TSL is a development aimed at picking up where these two left off."

Adjacent to Alabama Power Co.'s Gaston station at Wilsonville, Alabama, near Birmingham, the facility is managed by Southern Company Services, Inc., a subsidiary (as is Alabama Power) of The Southern Electric Generating Co., Inc.; Catalytic, Inc., operates the plant.

The 6-t/d Wilsonville liquefaction plant stands today as the largest facility dedicated to coal liquefaction R&D in the country. According to Lebowitz, "Most of the research currently under way in the United States on liquefaction process improvements involves some form of two-stage liquefaction. Wilsonville is the only facility larger than bench scale that remains dedicated to coal liquefaction development and is thus capable of testing scale-up of improvements developed in laboratory and bench-scale units. No other facility contains the unique set of equipment that is available at Wilsonville."

Two-stage liquefaction

First operated in 1973 as a solvent-refined-coal pilot plant investigating production of low-sulfur solid material, the Wilsonville facility has since changed dramatically with the addition of several major components, particularly a catalytic hydrotreater that serves as a second chemical reactor—hence, TSL. Kerr-McGee Corp.'s critical solvent de-ashing (CSD) technique is employed as an intermediate step to remove solid residues and ash before hydrogenation takes place.

In TSL the thermal dissolution reactor and the catalytic hydrotreater can be configured to operate either independently or in an integrated mode. When decoupled, there is no recycle of material from the hydrotreater to the thermal dissolver or to the CSD unit. The process produces either a high-melting-point solid product with less than 0.3% sulfur (the EPA limit for most utility oil-fired boilers) or a synthetic liquid similar to No. 6 fuel oil.

But TSL's versatility as a synthetic fuel producer is most evident when the reactors are run in the integrated mode. In this mode, the high-boiling oils from the catalytic second stage are used as the process solvent in the thermal stage; distillate solvent from the thermal stage is hydrogenated in the catalytic hydrotreater.

Such an arrangement affords several advantages: improved catalyst performance, greater liquid fuel yield, and improved product quality. The severity of operating conditions (temperature, pressure, and exposure time) in both the thermal and catalytic stages may be varied to achieve a range of useful products, mainly high-quality distillates with less residual oil component and fewer gaseous by-products.

The ability to carry out the catalytic reaction at lower temperatures (680–730°F, 360–387°C) than have been traditionally used (825–850°F, 440–454°C) is an important achievement to chemical engineers, such as Lebowitz. "At higher temperatures you get undesirable side reactions that yield light hydrocarbon gases instead of liquids. These gases contain hydrogen that isn't incorporated in the liquid product. The less gas that is produced, the less hydrogen is required in the liquefaction process and the greater is the distillate yield."

Presumably, more-selective production of liquids will translate to lower product cost. During recent tests at Wilsonville with Burning Star coal, 11–12 lb (5.0–5.4 kg) of high-quality distillate fuel oil were typically obtained per pound of hydrogen consumed. This represents a substantial improvement over the previous generation of processes, which operate in the region of 7–9 lb (3–4 kg) of product per pound of hydrogen. The improved results were obtained even when using a catalyst of advanced age.

But integrated operations to date have been carried out on a very limited scale. The Wilsonville facility's nominal feed capacity of 6 t/d is a far cry from the 20,000-t/d capacity that would likely be required of a commercial-size plant. So estimates of achievable product cost at this point remain conjectural. "We think that with the quality of the products that can be made, they'll be less expensive than coal-derived liquid fuels produced by other means," says Lebowitz, "but how much is unclear. The cost will be competitive with other synthetic fuels but will still be more expensive than today's $30/bbl oil."

Results from Wilsonville have been very encouraging. Most of the research effort last year was devoted to screening the effect of integrated-TSL reactor variables, principally the type of thermal (first) stage. C–E Lummus Co., under contract to DOE, performed early laboratory studies on one version that used a short contact time plug flow reactor. The first Wilsonville TSL run followed this approach. Subsequent tests showed that more liquid product could be recovered by using a well-mixed thermal reactor operated at a somewhat lower temperature.

Private companies active in this area include Kerr-McGee; C–E Lummus; and Cities Service Co.; Hydrocarbon Research, Inc., which supplied the expanded-bed hydrotreater at Wilsonville and has its own version of TSL; and Chevron Research Co., a subsidiary of Standard Oil of California, Inc.

Combustion and handling

As more liquid fuel product emerges from the process stream at Wilsonville, researchers will be conducting more combustion tests of the fuel to evaluate its performance in a utility oil-fired boiler environment. Early results of some bench-scale combustion tests, using a residual fuel oil produced at Wilsonville in the decoupled TSL mode, were presented at the Eighth Annual EPRI Contractors' Conference on Coal Liquefaction in May 1983.

Indications are that although particulate loading from TSL fuel oil was comparable to that of No. 6 oil, nitrogen oxide (NO_x) levels with TSL oil were 400–500 ppm greater than for No. 6 oil. KVB, Inc., under EPRI contract, reports that staged combustion of TSL oil reduced NO_x by 50% while increasing particulate emissions. On the other hand, optimization of the combustor atomizer during single-stage combustion significantly reduced both NO_x and particulate emissions.

The high nitrogen content of the fuel (0.7%) derives from the composition of the

LIQUEFACTION BASICS

Several approaches to coal liquefaction have been developed by government and private industry in the United States and abroad over the last decade. In all of them, powdered coal is mixed with a solvent and treated with hydrogen in a chemical reactor at high temperatures (700–850°F, 370–450°C) and fairly high pressures (2000–3000 psi, 13.8–20.7 MPa).

Recent work at the Wilsonville Advanced Coal Liquefaction R&D Facility has contributed to a more sophisticated, though still incomplete, understanding of the chemistry of coal liquefaction. In addition to basic process improvements that have been demonstrated at Wilsonville, related projects have investigated the interaction between coal and the coal-derived solvents that are used to convert powdered coal to soluble material.

Research has shown that the solvent plays an important part both in catalyzing the thermal dissolution of coal and in transferring hydrogen to the liquid molecular structure. In one respect, competing liquefaction techniques represent different approaches in applying the solvent.

The EDS process employs a solvent that adds, or donates, the hydrogen. Another, the H-Coal process of Hydrocarbon Research, Inc., adds hydrogen directly, with the chemical reaction speeded by a catalyst.

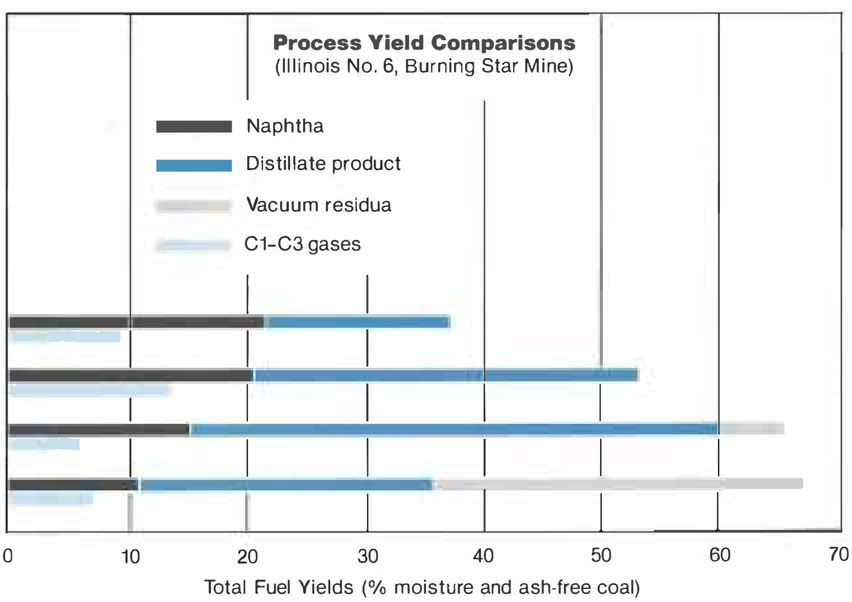
In TSL, the conversion of coal to distillable products takes place in two reactors in two distinct stages: one, a thermal dissolution stage; the other, a catalytic hydrogenation stage. H-Coal uses only one reactor stage. The EDS process flowsheet shows two stages; all the coal conversion, however, takes place in the first stage. Solvent hydrogenation occurs in the second stage.

Separation of ash residues and other solids from the coal-derived liquid represents another basis for comparing different liquefaction processes. Two-stage liquefaction requires a separation of nondistillable liquid product from the ash and unconverted coal. In the H-Coal and EDS processes, solids and nondistillable liquid are not separated. In the Wilsonville configuration, solids are separated before the product is fed to the hydrotreater. Other groups (such as Chevron and Hydrocarbon Research) are developing configurations that separate solids from products of the hydrotreater rather than from the feed.

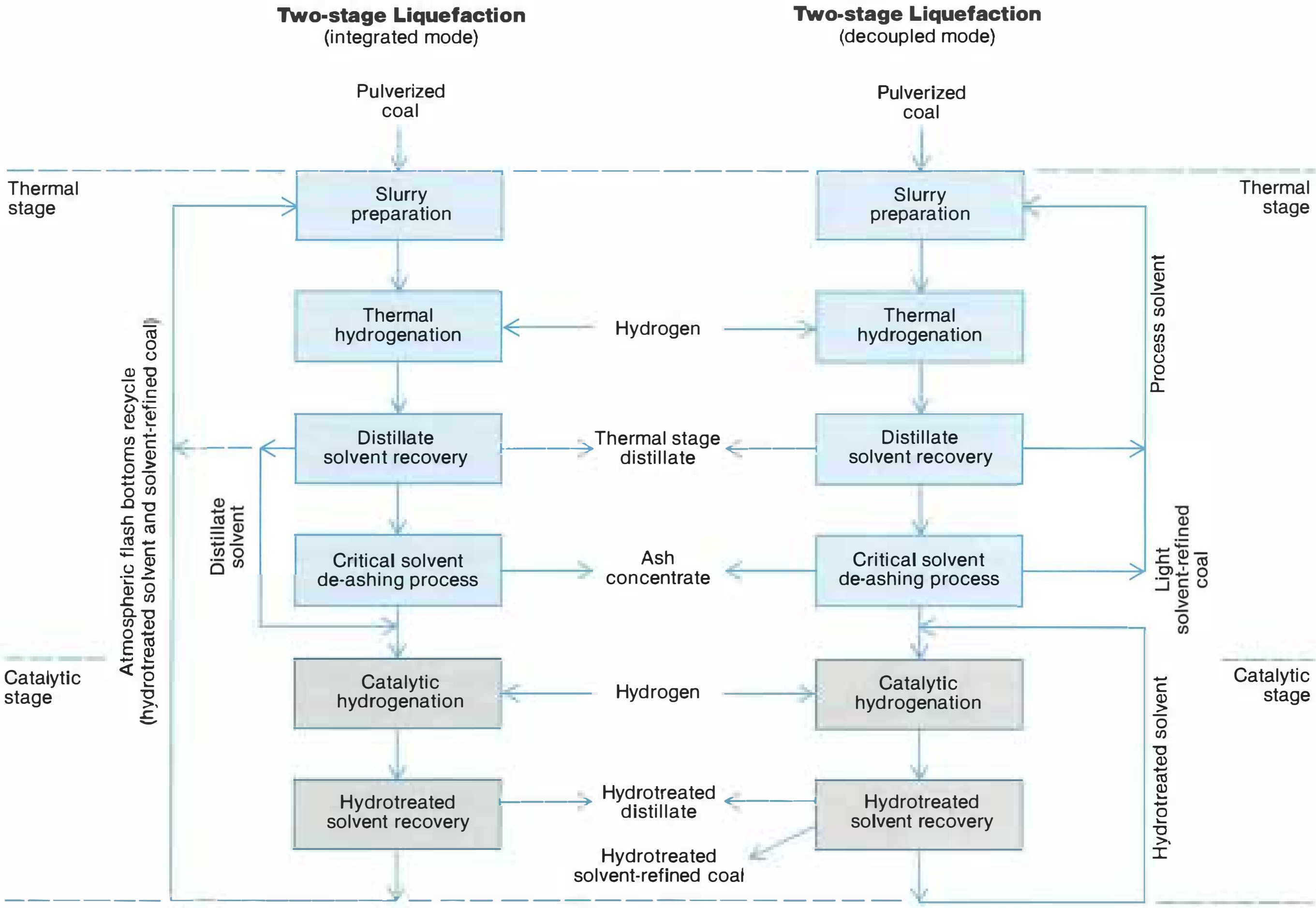
The differences in process design between TSL and other liquefaction approaches add up to several advantages for TSL: the catalytic reactor requires significantly less-severe reaction conditions of temperature and pressure; the efficiency of hydrogen consumption is greater; the mix of distillate products that can be made is more flexible, and these products are higher-quality fuel oils.

In addition, two-stage liquefaction produces more liquid per ton of coal than other direct techniques. Overall recovery of liquids is increased by 10% (or more of moisture- and ash-free coal), while light gaseous by-products are reduced by 50–75%. □

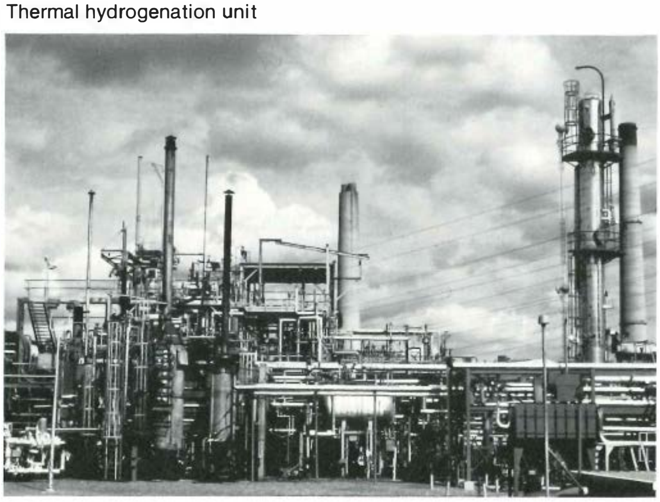
The yields of four coal liquefaction processes are compared, showing the relative mix of fuel products that can be made with each. Integrated two-stage liquefaction (ITSL) shows the greatest yield of high-quality distillate fuel oil suitable for firing in utility boilers and the lowest percentage of undesirable gaseous by-products. An additional advantage of ITSL is that such process conditions as temperature, pressure, and exposure time may be varied to produce a flexible slate of products.



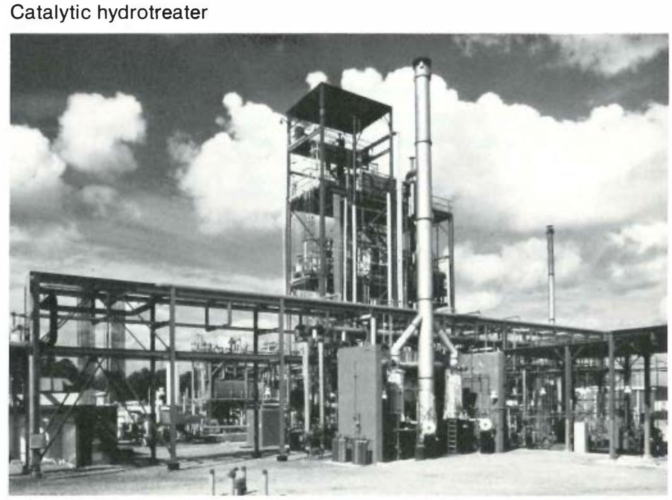
The process steps in two-stage coal liquefaction are similar for both integrated and decoupled operations at the Wilsonville, Alabama, R&D facility. In both configurations, the first stage involves thermal dissolution and hydrogenation of pulverized-coal slurry; in the second stage, a catalyst is used to promote further hydrogenation. When the stages are decoupled, there is no recycle of hydrotreated product to the thermal stage. In the integrated mode, high-boiling oils from the catalytic stage are used as process solvent in the thermal stage, and distillate solvent from the thermal stage is sent to the catalytic hydrotreater. This allows a variable slate of distillate products.



Thermal hydrogenation unit



Catalytic hydrotreater



coal. Fuel oil produced in integrated TSL, however, shows greatly reduced nitrogen content (0.1–0.2%); NO_x emissions from combustion are thus anticipated to be no higher than for comparable petroleum products.

Another area of research focus at Wilsonville relates to the handling properties of TSL oil. Some coal-derived liquids contain 4–6 ring polycyclic aromatic hydrocarbons (PAH), which can promote tumors in laboratory animals. Compounds of PAH containing nitrogen in coal are known to be responsible for most of the biologic activity in coal-derived liquids; these compounds have been detected in many coal liquefaction materials.

Research conducted for DOE at Battelle, Pacific Northwest Laboratories indicates, however, that more than 99% of the genetic activity of liquids from several different coal liquefaction processes (including Wilsonville TSL product from the decoupled operating mode) is contained in the distillate fractions boiling above 700°F (371°C). The high-boiling fraction of the integrated-TSL product, however, has a lower nitrogen content and reduced genotoxicity compared with similar fractions from other liquefaction products. Microbial mutagenicity tests of integrated-TSL products indicates that the active constituents are removed from distillates boiling as high as 850°F (454°C).

Future research

So far, most of the TSL production tests at Wilsonville have used a single bituminous coal (Illinois No. 6, Burning Star Mine). But because the chemical composition, Btu content, and quality of coal can vary greatly according to where it is mined, an important part of process development in coal liquefaction is to establish operability by using a range of coals as feedstock. The 1984–1986 research plan calls for testing a second bituminous coal and at least one lower rank (higher moisture content) coal.

A major area of research focus in the coming years relates to the catalyst that aids in hydrogen donation in the second stage of TSL. Tests to date have involved observing and recording the process performance over time, using a single catalyst charge in the hydrotreater. This is the preferred mode in process development, but ash and impurities in the coal that are not removed by the CSD eventually foul the catalyst. Commercial-size TSL plants would regularly add and withdraw catalyst to maintain constant performance. The Wilsonville research plan includes at least two long runs in which the catalyst will be changed out as part of the process run.

Also in the next two years, catalyst formulation will receive special attention. The most recent tests used a commercially available nickel molybdenum catalyst developed originally for another purpose by Shell Oil Co. Although the catalyst performed well (for example, in one test run, appreciable catalyst activity remained after processing about 1400 lb [635 kg] of feed per pound of catalyst), researchers believe even better performance could be achieved with a specially formulated catalyst.

"DOE and EPRI will be sponsoring work that may turn up a better catalyst," comments EPRI's Lebowitz. "Catalysts are usually very specific in application. We expect further process improvements will derive from an improved catalyst." The research plan calls for testing two as yet unchosen alternative catalysts at Wilsonville.

Reducing fuel supply uncertainty

Results to date from the Wilsonville Advanced Coal Liquefaction R&D Facility have demonstrated the feasibility of producing liquid fuel oil products that can be readily substituted for conventional petroleum-based fuels used in power generation. The necessity of establishing the lowest-cost route to coal liquefaction in the United States is recognized as having important value to the utility industry in that it reduces the uncertainty in future fuel supply by providing a proven alternative. Success of the Wilsonville research plan in the next two years could hasten the time when coal liquefaction products become commercially competitive. ■

Further reading

Proceedings of the Eighth Annual EPRI Contractors' Conference on Coal Liquefaction. January 1984. EPRI AP-3366.

Proceedings of the Seventh Annual EPRI Contractors' Conference on Coal Liquefaction. November 1982. EPRI AP-2718.

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This article was written by Taylor Moore. Technical background information was provided by Howard Lebowitz, Advanced Power Systems Division.

Grant Thompson: Pricing for Conservation

A lot of resource waste—and a lot of confrontation—could be avoided if we were more consistent in allowing market-level prices to prevail, according to this environmental lawyer and member of EPRI's Advisory Council.

Conservation is Grant Thompson's first love. Conservation is also a professional value, his practice as a senior associate and director of the energy program of The Conservation Foundation in Washington, D.C. Understandably, conservation establishes the tone and the substance of Thompson's role on EPRI's Advisory Council as well.

Thompson's day-to-day work involves rigorous fact finding and analysis for policy studies, which are the basis for published papers, speeches, and congressional appearances. But solving conservation problems today has to include viewpoints and value systems as much as volumes and tonnages, so Thompson looks for viewpoints on industry and government panels and boards. "It's considered a central part of my job," he says, "to be a member of groups like the Advisory Council."

Such participation cuts both ways, Thompson adds. "It also creates opportunities to explain some of our conservation research." But he does not shoot from the hip. Although reporters often call The Conservation Foundation for topical comment, "We have an old-fashioned rule that if we haven't studied something, we keep our mouths shut. There's no doubt that some people consider us very straight-laced and starchy."

Law school for what?

Three or four hours with Thompson reveal not only a conservationist but someone who is in every thoughtful way an environmental protectionist as well. Yet he and his organization do their work without the adversary tools of litigation. That's a tall order for a man with an Oxford education, a law degree from Yale, and a reasonable stint of corporate law practice in his not-too-distant background.

Thompson finds the Foundation's approach agreeable because he also has the quiet and deep-running convictions of a Quaker. As he puts it, "I'm not a confrontational person. Quakers believe there's always truth to be found, but that someone else may see it more clearly, so there's an obligation to listen carefully to the other person. In fact, you have to consider that both of you may be wrong and that there's some different way you can discover together."

Thompson's three years at Oxford began almost as the whim of a Pomona College history graduate. But in quick succession he experienced the fear of a system that has no mandatory classes and the luxury of unlimited time for reading and discussion. "They give you so little to do that out of boredom you educate yourself. And because the faculty, library, and student resources around you are so good, you come out with a fine education." For Thompson, that meant bachelor's and master's degrees in jurisprudence, which he topped off with an LLB at Yale in 1967.

While at Yale, Thompson knew several students who would later form the core of the Natural Resources Defense Council, a major public interest law group in environmental matters. But Thompson at the time chose a corporate law practice in Cleveland, where he honed his skills as a researcher and brief writer for four years. "The other attorneys loved working with me," he recalls, "because I could take their legal citations and arguments and write them into smooth and often convincing briefs."

Thompson still likes writing. "I love to take a complicated series of ideas and see if I can communicate them to people and make a difference." As an aside, however, he recalls when his nine-year-old son visited his office frequently and later told a friend, "Daddy's a typist."

By 1971 Thompson was uncomfortable in Cleveland, envisioning (as he puts it) a future tombstone with his name and dates on it and the epitaph, "He saved the XYZ estate $2 million." Along with several other environmentalists, Thompson had by then revived the Sierra Club chapter in northern Ohio, and it was thus clear that corporate law practice was not serving his central interests. An oft-spoken ethical injunction from his mother became pivotal. "She was a powerful influence on many people because of her ability to pose what Quakers call queries. A query is an unsettling question, sort of a burr in your soul." In Thompson's case, the burr was simply, "Are you fulfilling your obligation to make the world better?"

Deciding to turn to environmental law, Thompson intuitively selected Washington, D.C., moved there with his family, and as he says, "lucked into the perfect job" as associate editor of the *Environmental Law Reporter,* published by the Environmental Law Institute.

Influences on viewpoints

Thompson is offhand about his specific professional experience since then. "You read of people who say they planned their careers. I lurch and stumble from one thing to another." The Environmental Law Institute proved to be, in a phrase from business usage, an excellent positioning situation. Thompson became familiar with environmental issues of outer continental shelf drilling in work for the Council on Environmental Quality, "and because I was an environmentalist who knew something about energy, I lurched into work with Resources for the Future, Inc., on a book about nontechnologic research areas related to energy." (Hans H. Landsberg; John J. Schanz, Jr.; Sam H. Schurr; and Grant P. Thompson. *Energy and the Social Sciences.* Baltimore: Johns Hopkins University Press, 1974)

Knowledge and associations in that work brought Thompson to the attention of the governors of Washington, Oregon, and Idaho, "and that caused me to stumble into a 1974 consultancy on energy conservation policy with the Pacific Northwest Regional Commission." For the next four years Thompson was a fellow and director of energy research at the Environmental Law Institute, and since 1978 he has been with The Conservation Foundation.

Although modest in talking about his own career progression, Thompson knows there are influences and circumstances in everyone's life that cannot be trivialized as lurching and stumbling. Family setting, hometown, schools, jobs, and profession color one's views, affect one's ordering of facts. So do the times.

Some of these influences are intentional, known to the person and explainable to others—for example, Thompson's training in the Religious Society of Friends, the Quakers. Other influences are more subtle, Thompson says. "I came of political age in the sixties. When my children get to be interested in such things, I know I'll have trouble telling them what the sixties were really like. We carry a kind of invisible imprint. It was the same with my father, who came of age during the depression and would say to me, 'You'll just never understand.'"

Even so, Thompson feels it is important to be conscious of one's conditioning. He suggests that today's problems are as much in people and their attitudes as in the subjects that engage them. He mentions population pressure, observing how it leads to fears of shortages of energy and materials at prices people can afford. And the problem is qualitative as well as quantitative. "This country—this world, really—has to think about the degradation that comes to all of us by having so many of us."

Attitudes toward environment

Thompson characterizes two extremes among resource analysts, those who see endless possibilities of resource substitution and those who see a bottom to every barrel. "I don't find myself in either camp, but sometimes I do worry about the quality of life as we put more and more pressure on resources—creeping pressures—even with electricity. It has done wonderful things for our life, but we pay the costs. I think one of the lessons of the late sixties and the seventies is that we have a lot of environmental costs piled up, and we'll have to invest social capital to pay them."

Social capital? Thompson explains that

> "I worry about the quality of life as we put more and more pressure on resources. One of the lessons of the late sixties and the seventies is that we have a lot of environmental costs piled up, and we'll have to invest social capital to pay them."

his term includes money but, even more important, management interest and attention—new responses to new situations and new societal perceptions.

Thompson invokes the example of power plant emission controls. As he sees it, there is a clear opportunity for utilities simply to accept the importance that society places on clean air. "The job isn't how to fight it; the job is how to do it elegantly, to come up with better ways, and to take pleasure from it.

"We need managers who are really inquisitive about the long-range interest of the society they serve," Thompson continues. "Utilities are the perfect institution for developing such a view because they're in it for the long term. There's almost no other industry that builds production facilities to last forty years."

Thompson knows he is not pointing to an easy future. "Accountants. Investors. Wall Street is king today. There's a lot of worry in many circles about how America is locked into the short-term, year-to-year bottom line." This observation emphasizes the contradiction of long-term and short-term value systems that utilities must contend with.

Thompson does not foresee fast change, because "it obviously is the nature of business to be conservative. Businessmen talk about taking risk; but, in fact, the good businessman works hard to minimize risk, to make things fall his way. It's called planning; it's called strategy. Business will always be conservative because it has to worry about continuity."

But there is a need to distinguish conservatism from resistance to all change. Thompson cites early child-labor and worker-safety reforms in England, where industry insisted that change would wreck the economy. And in this country, in this century, Thompson notes, court and legislative victories by groups like the National Resources Defense Council, the Environmental Defense Fund, and the Sierra Club were necessary for environmental issues to be taken seriously.

The running example of plant emission controls reminds Thompson to express his view on paying for acid rain cleanup. "It isn't a matter for taxpayers," he says. "Economics teaches us that the people who impose costs should bear those costs. That means power consumers, even for retrofitting old plants, which in a sense is paying for past events they had nothing to do with."

Pressed for the distinction between taxpayers and ratepayers, Thompson acknowledges the overlap, "but cleanup is a cost of using electricity, you know. It's not a cost of being a citizen."

Pricing for conservation

Once Thompson starts to talk about ratepayers, he is hard to stop. "I'm a rate groupie," he explains. "Groupies are those fanatics who attach themselves to rock bands. I'm hooked on what people used to call the dullest part of the utility business—the rate department, full of clerks in long rows with hand-cranked adding machines.

"I'm accused of being a born-again economist, too, because I think market pricing tells people the impact they have on resources. I'm interested in how the market can help allocate resources efficiently." The OPEC oil embargo and price increases of 11 years ago illustrate Thompson's thesis: gasoline lines and the accompanying feeling of helplessness disappeared as price-induced conservation took over, working so well that OPEC's prices today are soft.

Thompson's concern is that electricity rates do not respond as do other prices in the national economy. "They're based on costs already incurred, thus signaling the past, not the future. As a result, electricity is underpriced much of the time today."

More or less parenthetically, Thompson adds that his thinking on electricity is elaborated in a 1982 study that he codirected with Thomas Schelling of the Kennedy School of Government at Harvard University. Titled *Energy Prices and Public Policy*, it was published jointly by The Conservation Foundation and the Research and Policy Committee of the Committee for Economic Development.

The impact of higher fuel costs in the past 10 years has been an incentive for electric utility innovation and R&D, Thompson acknowledges. But there could be more, he says. "We've seen a little conservation in electricity—and a lot elsewhere. If the price signals in electricity were more nearly correct, we'd see tremendous technology innovation, innovation in capital structure, innovation in load management and time-of-use rates."

To hear Thompson tell it, the outcome would be efficiency and economy all around; the problem is to get from here to there. As it is, he points out, "You can buy a dishwasher that has a 12-hour ad-

"Electricity rates are based on costs already incurred, thus signaling the past, not the future. As a result, electricity is underpriced much of the time today."

vance timer, but its only advantage today is leveling your hot water demand. The real incentive would be cut-rate electricity in the off-peak hours."

For Thompson, the environment is more than the natural ecological web. As an advocate of market pricing for energy, he emphatically includes money among the resources to be conserved. But, he cautions, "One of the blinders on Americans today is our unquestioning love of markets, as if they alone defined the desirable society. Markets aren't the only instrument of policy. We have governments, in part, for the very reason that markets don't do some of the things we consider important."

Thompson speaks of instances where the market fails to apply pressure or imposes a cost on the wrong person. He suggests the example of a new office building, its HVAC system specified by the developer on a first-cost basis but paid for by tenants who have no choice in the matter. The market in such a case favors low first cost, not low overall cost.

This is one situation that needs public regulatory guidance, Thompson acknowledges. But he contests another that is often cited. "The poor do not need cheap electricity. They don't need energy stamps. Both those approaches eliminate their incentive to choose, as the rest of us do. What the poor need is money: well-administered welfare. I applaud economics in its place, especially in electricity pricing, but we can't duck our community responsibilities."

R&D to save electricity

If market factors were to play more of a role in electricity pricing, and if that would be an incentive to technology innovation, what sort of R&D should get attention? Thompson is most intrigued by research that helps the electricity user, because it goes beyond the utility industry alone and serves society in a broad, long-range sense.

Integrated lighting systems and controls for buildings are candidates for more R&D, Thompson believes, as are the light characteristics and levels attainable with various lamps. Another opportunity is fractional-horsepower motors; they're used everywhere, and Thompson was interested to learn from EPRI that Japanese industry is conducting extensive R&D to improve them. "Couldn't EPRI somehow coordinate or push along a counterpart program?"

As the research organization for an entire industry, EPRI may be unique today, Thompson believes. "For years, Bell Laboratories was a hotbed of innovation. Now that the phone company is broken up, it will be a test of whether nonregulated industry can sustain innovation on the same scale." But comparing EPRI directly with Bell is pointless, Thompson acknowledges, because from the beginning EPRI has emphasized technology development more than basic science. "To the extent that a country lawyer can understand what engineers say and write, hardware and process technology is what EPRI does best."

Then there is the other side of the coin. Thompson is uncomfortable about what he sees as a fascination with models and modeling at EPRI. "Forecasting models and demand models are beguiling, and we too often hear, 'Our model demonstrates that such-and-such is true,' without a clear acknowledgement of the necessary qualifications. Even the best model assumes relationships to be firm that in the real world are fragile and only inferred from scanty data." Most of all, Thompson fears that externalities cannot be well enough identified, much less weighted properly, for predictive models.

"Thirty years ago, if you had asked about the environmental effects of a power plant, you might have learned, among other things, that the condenser heated up the river. Nobody would have thought anything of it. There was no sense of thermal pollution as an adverse impact." Thompson wonders if we can see ahead any better today. Truly useful modeling, he believes, requires that you not only understand the relationships but know all the variables, their weights, and how society's values may change.

Useful advisory tasks

Thompson has now been with EPRI's Advisory Council for two years, just half a term. Does it advise? How well does it function? Thompson's responses are not uncommon. Council members learn quite as much as they advise, he reports—perhaps a little more. There are reasons. One is that the Council, unlike EPRI's industry advisory groups, is intentionally selected to represent disparate interests or constituencies. Some backgrounding is necessary, just to give the Council a baseline understanding of electric utilities. Even so, says Thompson, "I think EPRI has a tendency to overbrief us.

"Also," he continues, "the people at EPRI occasionally seem a bit defensive about a Council suggestion or question. It's as though absolutely every question we raise must be answered; but that's not really so." Thompson recognizes that this pattern is not intentional, but it takes away from Council discussion time, and, he adds, "it has a kind of chilling effect because you begin to wonder whether you're always wrong."

> "If the price signals in electricity were more nearly correct, we'd see tremendous technology innovation, innovation in capital structure, innovation in load management and time-of-use rates."

There is little sustained work on Advisory Council business, Thompson feels. "Our meetings are sort of isolated events, and I think EPRI loses some of the best kind of advice it could get." He therefore favors an Advisory Council committee that would think through and document some subject, such as EPRI's role in end-use research. "Discussion is often ephemeral. It would be nice to think through and write a connected, thorough white paper."

Thompson mentions another way the variety of expertise on the Council might be used. "I'm on a board of the National Academy of Sciences, and the Academy staff frequently calls me to name candidates from my field for various kinds of studies or review panels." Good-naturedly characterizing himself as a "cheap date with an enormous Rolodex file," Thompson says he would welcome the opportunity to help EPRI program managers in similar fashion.

Referral of expertise is a special faculty of the Scientists Institute for Public Information, another organization that commands Thompson's interest and time as a board member. Thompson describes SIPI's main activity as a media resource service, a computer data base of scientists and engineers who have agreed to furnish background, answers, and interpretation in many disciplines. The SIPI staff is accessible at a nationwide toll-free telephone number; it takes questions from reporters, locates available respondents, and then directs questioners to them, often within an hour. "A terrific capability," says Thompson. "Walter Cronkite says that if this service didn't exist, we'd have to invent it."

Taking part in agreements

Grant Thompson exhibits a pervasive sense for personal and group relationships and an enthusiasm for accurate communication. Almost predictably, he is involved in the practice of conflict resolution. Indeed, The Conservation Foundation has for several years formed and facilitated dialogue groups for settling policy disputes; it has published books, most recently *Settling Things: Six Case Studies in Environmental Mediation* (by Allan R. Talbot, 1983); and it has absorbed an organization called Resolve: Center for Environmental Conflict Resolution (whose founder, John Busterud, was an early member of EPRI's Advisory Council).

Thompson chaired a dialogue group on the problems of low-level radioactive waste, bringing together such viewpoints as those of a nuclear power professional from Yankee Atomic Electric Co.; a League of Women Voters member, angry about a mismanaged disposal site at West Valley, New York; a Washington state regulator, responsible for the site at Hanford; and a county commissioner from Wisconsin, where sites were being considered. A major task, Thompson says, was "to find out what things we could agree on, what sort of report the group felt comfortable putting together to represent its shared views."

The process of reaching such agreements, and signing them, is difficult, Thompson emphasizes, "because you start out with each side afraid of losing something it cares a lot about. In fact," he points out, "you don't have good negotiation, or fruitful mediation, or even useful policy discussion if one side feels that it holds all the cards. There has to be a kind of nervousness about the outcome on both sides."

Asked about the possibilities for invoking mediation or a policy project on acid rain, Thompson is not encouraging. "You have to capture things at the right moment. It goes back to that question of power. Right now the environmental community, broadly speaking, seems to have more cards than the utilities."

Nevertheless, Thompson holds fast to his faith in the value of discussion between people and groups that hold conflicting views. He turns to the Religious Society of Friends for an unusual example. "Back in the 1750s, when traveling Quakers accepted free meals and lodging from their hosts, one such sojourner insisted on paying whenever he stayed with a slaveholding Quaker family. He wouldn't accept the free services of slaves, and by his example he helped

"One of the blinders on Americans today is our unquestioning love of markets. Markets aren't the only instrument of policy. We have governments, in part, for the very reason that markets don't do some of the things we consider important."

many of the Quakers work through an issue that eventually divided the whole country."

The important lesson in this—for secular mediation today—is the strength of the ultimate resolution that comes from being a party to it. "Once the Quakers themselves found consensus, they were totally clear on it. They were even willing to break the law—run the underground railroad, for instance—because they had worked things out themselves."

Thompson's message has to do with what he calls a tension between the concepts of adversary action and cooperation. Both denote ways to settle disputes. But the former often yields only grudging compliance, while the latter frequently produces new initiatives.

This difference in outcome does not depend on subject matter or choice of forum—litigation or mediation. The difference is in the character of the agreement reached. Participants in conflict resolution have changed their attitudes about the facts. As Thompson puts it, "They no longer fight, and the reason is that they've created the agreement themselves. It's theirs, and they believe in it." ■

This article was written by Ralph Whitaker and is based on an interview with Grant Thompson.

NSTA: Enriching Energy Education

For 10 years the National Science Teachers Association (NSTA) has prepared materials on energy for use in school curricula, educating teachers and students on the complexities of energy issues.

American consumers received a crash course in energy supply and demand economics in the early 1970s while waiting in lines for gasoline. This quick study caused many consumers to reevaluate their own and the nation's energy use and resulted in energy conservation programs, energy-efficient cars and appliances, and a renewed emphasis on making the best use of domestic resources. The lessons of the oil embargo also reached the nation's school systems, where they were analyzed and discussed in science, civics, political science, and social studies courses.

A lack of teaching materials focusing specifically on energy, however, made it difficult to communicate this relevant topic to students. NSTA, a membership organization of 21,000 science teachers, saw the need and, working with the federal government, began the development of energy resource materials. It was an appropriate place for energy education to start. Founded in 1944 and located in Washington, D.C., NSTA is the nation's largest education association devoted to improving science education on all levels—elementary, junior high, high school, and college.

The energy education program began at NSTA in 1974 with a contract from the U.S. Office of Education's Office of Environmental Education. John M. Fowler, NSTA's project director for the Energy-Enriched Curriculum Program, directed this initial project, as he has all others since. With a doctorate in physics and many years of university-level teaching behind him, Fowler embarked on translating his knowledge of energy into a form that was both useful and understandable to teachers and students alike. "I knew from the start that integrating energy issues into an existing curriculum would strengthen it. Understanding energy processes involves all the academic disciplines and brings students to a greater understanding of how the real world works. To properly teach energy issues, the science teacher can't ignore economics and social consequences and the social studies teacher can't ignore science."

NSTA's first contract with the U.S. Office of Education resulted in three publications prepared by Fowler: *Energy Environment Source Book*, a comprehensive background text written for teachers; *Energy Environment Materials Guide*, an annotated bibliography of energy and environmental literature with a set of grade-level reading lists for students; and *Energy Environment Mini-Unit Guide*, a collection of sample activities for school classrooms.

These materials had a wide distribution to the school systems through money provided by the Federal Energy Administration (FEA), and close to 15,000 sets were sent to chairmen of both science and social studies departments. The *Source Book* proved so popular that it has been reprinted twice and sales (in addition to the original 15,000) have now reached 30,000. Its sales are the largest of all NSTA publications.

Energy-Enriched Curriculum

The positive reception of these early energy education materials encouraged Fowler to pursue a longer-range program. In 1976, therefore, NSTA began another materials development project, the Project for Energy-Enriched Curriculum (PEEC), this time with funding by the Energy Research and Development Administration (ERDA) and later funded by the Education Programs Division of DOE. The key to this second project was to create "infused" materials—those that could be blended into the existing school curriculum rather than as add-on or supplementary materials.

Fowler explains this concept: "We knew, for example, that in the second or third grade part of the curriculum focuses on living in a community. Therefore, we developed a packet on 'Community Workers and the Energy They Use,' which highlights energy helpers, such as the oil supplier, the gas station attendant, and the meter reader."

Another example of these curriculum packets is one prepared for the junior high school student on "How a Bill Becomes a Law to Conserve Energy," focusing on the legislative process and using the example of a congressional hearing on the 55-mph speed limit bill. There is also a packet on "U.S. Energy Policy: Which Direction?" for grades 11 and 12, which discusses the executive arm of the federal government and the ways national policy is formulated. Packets were also developed on "Mathematics in Energy," "Energy Transitions in the United States," "Networks: How Energy Links People, Goods, and Services," and "Agriculture, Energy, and Society." Fifteen packets were produced by NSTA and were then printed and distributed free by DOE. Another 20 packets have been prepared but are currently unpublished.

Fowler again emphasizes that these packets are interdisciplinary. "The very nature of energy education is interdisciplinary, for energy affects all the different aspects of our lives—social, economic, and political. For example, to understand how the oil embargo of the 1970s affected an individual family's need for gasoline, a student would have to apply knowledge from history, political science, social studies, economics, and math, as well as the science disciplines. And this helps students understand the ethical decisions that must be made in the world today."

The classroom packets cover all the major concepts in energy, environment, and economics. Preparing materials on all these topics became, as Fowler explains, a hidden agenda for NSTA's energy education materials. "We decided that children need an early introduction to the abstract notion of energy. A puppet was developed who can change form from light to heat to motion. The puppet can also represent potential energy when resting or kinetic energy when active."

As the materials become more sophisticated in the higher grades, the classroom packets explain how different technologies convert energy from one form to another. In the high school materials, the two natural laws of energy are discussed—the first and second laws of thermodynamics.

Students are also introduced to the effects of energy production and consumption on the environment, including strip mining, oil spills, and acid rain. As part of this broadened view, economics becomes a factor in energy production and the whole concept of energy supply and demand is discussed, as in the packets on "Energy as an Investment Choice" and "Energy in the Global Marketplace."

"Inherent in this hidden curriculum is the fact that many of the problems of energy use are social issues. The scientific and technological problems of increasing conversion efficiency, getting new fuels from coal, and tapping solar energy sources pale beside the social issues. Science can be there to explain the technology and its impacts and to help uncloud the value judgment in the social area. The uninformed rhetoric of some of the antinuclear protestors and the exaggerated claims of some solar enthusiasts are evidence of unsuccessful science teaching," Fowler believes.

Development, Placement, and Use

The success of the NSTA materials, over one and a half million of which have now been distributed, is a result of the careful development process that the materials undergo. The classroom packets were written by science and social studies teachers during summer writing sessions. The writing sessions consisted of 10 teachers of various grade levels who worked in teams of three or four and produced four or five packets during a one-month writing session.

Each of the 35 packets developed was checked by at least three reviewers for both content accuracy and relevance to the curriculum. The packets also underwent classroom testing and were evaluated by the teachers using them. DOE also reviewed each classroom item, although the responsibility for technical accuracy rested with Fowler.

In addition to the teacher and technical review of the energy materials, NSTA

Fowler

also created a steering committee to provide oversight, objectivity, and additional review procedures. The committee was composed of educational representatives from all aspects of the energy community, including the American Petroleum Institute, Atomic Industrial Forum, Center for Study of Responsive Law, Edison Electric Institute, National Coal Association, Natural Resources Defense Council, and the Scientists Institute for Public Information, in addition to representatives of universities, secondary schools, and elementary schools. As an example of the thoroughness of this review process, it often took over a year to develop one packet and provide it to DOE for printing and distribution.

It is one thing to develop energy education materials, however, and another to get them out into the school systems where they can be used. Fowler found that one of their best distribution systems was through the education programs at electric utilities. "The educational representatives at many utilities have copied and distributed these materials; it gave them an entree into the schools in the service area by providing well-prepared materials."

Yet even with the free distribution of these packets and fact sheets, teachers must also be motivated to introduce energy education into the existing curriculum. NSTA sought to involve teachers in an energy education network by holding workshops that emphasize the urgency of teaching energy issues. To date, 20 or more of these workshops have been held.

As a follow-on to these initial workshops, NSTA also organized practitioner conferences, which were opened to teachers already teaching energy education or developing curriculum materials to introduce energy subjects. The practitioner conferences started a network of energy educators, allowing for an exchange of ideas and teaching practices.

NSTA also initiated a newsletter, *Energy & Education*, published five times a year, to help publicize this effort of integrating energy issues into the classroom. Teacher response to the newsletter has shown that there is a need that NSTA's energy education emphasis can fill.

"*Energy & Education* is in many ways our most important product. It's one way the science teacher, the social studies teacher, the educational manager of an electric utility or an oil company can feel they belong to a group of energy educators," Fowler comments.

Supplemental Materials

Fact sheets on alternative energy technologies are another component of PEEC. These are four-page units that serve as background readings for teachers, upper-level students, and the general public. These fact sheets have discussed the topics of biofuels, wind power, oil shale and tar sands, photovoltaic and solar-thermal energy, breeder reactors, nuclear fusion, energy storage, fuel cells, and new fuels from coal. There are 19 separate fact sheets and close to 3 million have already been distributed free on request from DOE.

However, with the recent cutbacks in the educational program at DOE these fact sheets are not currently available. NSTA recently updated each fact sheet but now has to find a way to print and distribute the revised version. "In addition to the updated fact sheets, we have also prepared 20 classroom packets that remain unpublished," Fowler explains. "Unfortunately, with the loss of the DOE funding, NSTA does not have the funds to print these materials and I am now searching for outside support to help us get these materials printed and into the schools."

In addition to these written classroom materials, NSTA has developed energy software oriented for the microcomputer. The computer programs are a supplement to existing junior and senior high school science and energy education programs. One game that should be of interest to utility educators is Power Grid, which simulates the actual operation of an electric utility. The student must bring power plants on-line to meet anticipated demand in as reliable and inexpensive a method as possible. Electric Bill explains to the student how electric bills are computed, how to read a utility bill, and what rate structures mean. Energy Conversions converts one unit of energy to another so demand trends can be compared, while Personal Energy Inventory provides students with an inventory of their own energy use and explains energy consumption. Fowler realized early that computers were going to play a major role in education and produced these programs under the DOE contract. He comments that they have had a tremendous reception and are often used by utility educators for teacher training sessions.

Teachers' Reaction

But how important do teachers themselves believe it is to teach energy education? To find out, Fowler and his staff conducted a national survey to gauge the current level of energy education. The survey was conducted for DOE at the end of the 1981–1982 school year. NSTA polled over 7000 educators, including elementary and secondary school principals; high school science, social studies, mathematics, and home economics teachers; and elementary school teachers.

The survey received a 22% general response rate and revealed that teachers devote a median average of eight class hours to the teaching of energy education. The topics most often studied, in rank order, were energy conservation (90%) and production technologies (conventional technologies, 63% and renewables, 59%). Of those educators responding, energy and environmental interaction was taught by 54% and energy and economics by 44%.

Activities involving energy topics are also fairly common on a schoolwide basis. Of the principals who responded to the survey, 34% reported holding science and/or energy fairs, 30% had energy-related field trips, 16% had school assemblies devoted to energy topics, 15% sponsored teacher workshops on energy education, and 5% participated in National Energy Education Day programs.

One of the more interesting results of the survey is that 70% of those teachers responding who teach about energy in their classrooms do it out of a personal conviction rather than as a curriculum requirement. And, most important, 90% of both teachers and principals surveyed felt that energy education should be part of their school curriculum.

What the Future Holds

Although the survey revealed that there is a market for energy education in the nation's school systems, NSTA's contract with DOE to produce these materials will run out this year. The budget reductions at DOE have depleted almost all funding for educational programs. Fowler hopes that the private sector, the electric and gas utilities, oil companies, coal companies, and other companies that are energy-related will continue to support education programs. "There is some evidence to support this hope. I've noticed that the energy industry associations have increased their educational activities; for example, the Edison Electric Institute holds an annual meeting of utility educational representatives, and the American Petroleum Institute and the American Gas Association are both producing more energy classroom materials." (In addition, EPRI has produced its own educational series, the *Energy Reporter.* Aimed at a high-school audience, the *Reporter* series discusses electricity-related energy technologies and is available for distribution by utilities in their local school systems.)

Fowler comments that electric utilities are one of the strongest supporters of these materials. "Utilities face quite a variety of problems and education is one obvious answer to them. Also, I know that many of the educational representatives at utilities are former teachers, and they know what schools need in the way of accurate and well-written materials.

"I also believe that energy education is alive and well out there. And it may become increasingly important. Many states are planning to increase the science requirements for students and such courses as Science in Society will probably result. These courses will have to include energy topics, for, as we all have seen, energy impacts our lives every day. And the next generation should be aware that these impacts will only increase." ■

This article was written by Christine Lawrence, Washington Office.

Acid Rain Studied in Streams

Dissolved aluminum is the focus of EPRI's laboratory and field research into the effects of acid rain on four Appalachian streams.

An EPRI study to assess the effects of acid rain on four mountain streams is under way in the northern and southern Appalachian Mountains. The three-year, $1.9 million project is studying the impact of acid rain on water chemistry and aquatic life, including the effects of sudden acidification during rainstorms and snowmelts. Oak Ridge National Laboratory, Cornell University, and Syracuse University are conducting the research.

Scientists are paying close attention to water chemistry, particularly the effects of aluminum. Many believe acid rain causes aluminum to filter at increased rates from soils into streams and lakes; when present in acidified waters, this metal may be highly poisonous to aquatic life.

A rare isotope, aluminum-26, is being used in laboratory studies to simulate the chemistry and movement of the more common forms of aluminum in streams and surrounding soil. The amount of the radioactive substance being used in the research (less than one millionth of a gram) represents 40% of the world supply. It was produced in a cyclotron at the Los Alamos National Laboratory in New Mexico.

Parallel field studies are monitoring two streams in the Adirondack Mountains near Old Forge, New York, and two streams in North Carolina, one in the Great Smoky Mountains National Park near Cherokee and the other in the Nantahala National Forest near Franklin. The northern and southern Appalachians were chosen for the study because many of these streams have a low acid-neutralizing capacity and thus are particularly sensitive to acid deposition.

In North Carolina, the streams are serving as natural laboratories for assessing the chronic effects of acidification on aquatic life. Scientists will be studying the decreasing acid levels as the water flows downstream. Bacteria, plants, bottom-dwelling animals, and fish will be examined on a regular schedule and when there are sudden changes in acidity caused by rainstorms and snowmelt. Detailed water chemical analysis will be made as scientists look for various forms of dissolved aluminum. Instruments have been installed in the streams to continuously record acid levels and other water chemistry changes.

Later studies will modify stream chemistry experimentally. Small amounts of acid and aluminum will be added in the field to assess their effects on stream organisms. The laboratory studies using aluminum-26 will be conducted under simulated environmental conditions to determine the element's natural pathways in acidified streams.

"In the past, much of the research on aquatic acidification has concentrated on lakes," notes EPRI Project Manager John Huckabee. "Because water quality alterations resulting from the atmospheric deposition of acids is likely to appear first and in greater magnitude in small upland streams, information on stream acidification is particularly important to our understanding of acid rain effects." ■

Coal Cleaning Technique Salvages Waste Product

A continuous, pilot-scale froth flotation circuit is now operating at EPRI's Coal Cleaning Test Facility (CCTF) in Homer City, Pennsylvania. The froth flotation process will allow power plant operators to use fine-coal products that were previously discarded as waste.

The froth flotation circuit is a water-based process that uses chemicals to float coal particles. Once floated, the clean coal particles are removed from a froth layer by mechanical paddles. The technique has been widely used as an effective means for concentration of metalliferous ores, but it has not yet been used extensively in the treatment of steam coals in the United States.

Froth flotation could allow utilities that clean coal to preserve more of the coal product. "With coal prices continuing to climb and the cost of building new power plants increasing, this process could enable utilities to maximize their return on investment," comments CCTF Project Manager Clark Harrison. In 1982 coal-fired plants accounted for more than half of U.S. electricity generation, and coal appears to be a major power-generating fuel for the future. For these reasons, Harrison projects that the use of the froth flotation technique could increase by 30–40% in the next 10 years.

The froth flotation cells recently installed at CCTF were developed under a Coal Quality Program study with the goal of making flotation a more efficient process for rejecting ash and pyrite sulfur impurities while maintaining a high Btu recovery.

The pilot froth flotation cell project has three primary objectives, according to Harrison: to improve froth flotation performance in cleaning steam coals; on the basis of laboratory data, to improve and develop new mathematical methods and models that will predict more accurately the performance of the process in a commercial plant; and to train coal preparation engineers and operators in the use of the froth flotation circuit. ■

Tower Tests Continue at TLMRF

The first tests of a tubular H-frame transmission tower were completed in December 1983 at the Transmission Line Mechanical Research Facility (TLMRF) in Haslet, Texas.

The tests confirm that the 128-ft (39-m), 31,000-lb (5.9-Mg) tower can withstand hurricane-force winds and other loads that might be encountered during its projected lifespan. They were conducted for the tower's owner, Florida Power & Light Co., and the manufacturer, Valmont Industries of Valley, Nebraska. These H-frame towers will be used on a 100-mi (161-km) segment of a 500-kV line between The Southern Company, in Georgia, and FP&L.

Owned by EPRI and managed by Sverdrup Technology, Inc., TLMRF is the world's most advanced center for the research and testing of transmission structures. Tower tests at TLMRF are more extensive and less costly than tests available to utilities from other sources.

Utilities send towers to the facility for testing and analysis. Together, the utility, fabricator, and TLMRF staff design a battery of tests that meet both utility and research needs. All results are made available to the tower fabricator and the utility after the tests.

The most extensive testing to date of a steel lattice transmission tower was successfully completed in October 1983 on a 120-ft (37-m), 13,000-lb (5.9-Mg) tower designed and built by Anchor Metals of Hurst, Texas. The tests verified that the state-of-the-art transmission tower can withstand design loads expected to result from weather, age, and conductor weight during its projected lifespan.

This type of tower will be used by Public Service Co. of New Mexico on its new 216-mi (348-km), 345-kV Eastern Interconnection Project between Blackwater Station and the B. A. Norton Line. ■

Electric Vehicle Group Seeks New Members

The Electric Vehicle Development Corp. (EVDC), a nonprofit organization formed to advance the development and marketing of electric vehicles (EVs), is seeking new members to gain broad utility representation. Other business and industrial organizations are being sought as associate members.

EVDC was formed last fall to work with manufacturers and others toward production of reliable, on-road electric cars and trucks in large numbers by the end of the decade. The corporation's nucleus consists of 26 utilities, representing 35% of U.S. electric generating capacity. William B. Harrison, senior vice president of Southern Company Services, Inc., will serve as chairman of the new venture, and John McLean, formerly a vice president at Wisconsin Electric Power Co., will serve as president.

EVDC's work is expected to demonstrate the R&D activities of EPRI, DOE, and others and to bridge the gap between technology developers and consumers. Its role is to develop specifications for an EV and to define early markets, with the goal of introducing a commercial fleet EV by the late 1980s. With expected improvements in battery technology and expanded support systems, EVs may penetrate the personal vehicle market in the 1990s.

The corporation's business strategy is to develop preliminary plans for national service and maintenance facilities, service and maintenance training programs, and technical manuals. EVDC will also provide a forum for the exchange of ideas, spurring industry communication.

Because EVDC is neither an R&D organization nor a manufacturer, however, it must rely on others to supply proven technology. EVDC will use EPRI's test results to select the most applicable technologies for vehicle production.

EPRI began its EV work in 1977. Its Electric Transportation Program funds testing and evaluation of vehicles and their related components, emphasizing the development of batteries and propulsion systems. This funding supports continuing laboratory, track, and on-road testing of vehicles, battery systems, and chargers at the Electric Vehicle Test Facility in Tennessee.

Many electric utilities have expressed interest in EV commercialization because EVs represent a significant new market for electricity. EVs recharged during off-peak demand periods can improve utility load factors, reduce average generating costs, and increase revenues without new investment in generation or transmission facilities. ■

CALENDAR

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

MAY

1–2
Seminar: Indoor Air Quality
Denver, Colorado
Contact: Gary Purcell (415) 855-2168

1–3
Annual Review of Demand and Conservation Program Research
Atlanta, Georgia
Contact: John Chamberlin (415) 855-2415

1–3
Mutual Design of Transmission Lines and Pipelines
Palo Alto, California
Contact: John Dunlap (415) 855-2305

2–3
Workshop: ARMP PWR and BWR
Dallas, Texas
Contact: Walter Eich (415) 855-2090

8–10
1984 Annual Conference: Clean Liquid and Solid Fuels
Palo Alto, California
Contact: Howard Lebowitz (415) 855-2517

9–10
14th Semiannual Meeting: ARMP Users Group
Jackson, Michigan
Contact: Walter Eich (415) 855-2090

15–17
Mutual Design of Transmission Lines and Railroads
Chicago, Illinois
Contact: John Dunlap (415) 855-2305

21–22
Seminar: Energy-Efficient Lighting
San Francisco, California
Contact: Stephen Pertusiello (415) 855-2171

JUNE

5–6
Seminar: Energy-Efficient Lighting
Baltimore, Maryland
Contact: Stephen Pertusiello (415) 855-2171

5–7
Symposium: State of the Art of Feedwater Heater Technology
Washington, D.C.
Contact: Roland Coit (415) 855-2220

7–8
Demand-Side Management: Strategic Planning and Marketing
St. Louis, Missouri
Contact: Ahmad Faruqui (415) 855-2630

19–21
Mutual Design of Transmission Lines and Railroads
Washington, D.C.
Contact: John Dunlap (415) 855-2305

20–22
PFBC: Recent Developments
Williamsburg, Virginia
Contact: Steven Drenker (415) 855-2823

25–28
8th Annual Workshop: EPRI Geothermal Power Systems
Seattle, Washington
Contact: John Bigger (415) 855-2178

JULY

10–12
Annual Review of Demand and Conservation Program Research
Seattle, Washington
Contact: John Chamberlin (415) 855-2415

AUGUST

13–14
Effect of Voltage Change on Energy Consumption
Dallas–Fort Worth, Texas
Contact: Herbert Songster (415) 855-2281

SEPTEMBER

11–13
Mutual Design of Transmission Lines and Railroads
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

20–21
BENCHMARK: A Chronological Generation Simulator
Boston, Massachusetts
Contact: Jerome Delson (415) 855-2619

26–28
Symposium: Demand-Side Management
New Orleans, Louisiana
Contact: Ahmad Faruqui (415) 855-2630

OCTOBER

15–18
Seminar: Fuel Supply
Kansas City, Missouri
Contact: Howard Mueller (415) 855-2745

16–18
Buildings and Their Energy Systems
St. Louis, Missouri
Contact: Orin Zimmerman (415) 855-2551

NOVEMBER

7–8
15th Semiannual Meeting: ARMP Users Group
Long Island, New York
Contact: Walter Eich (415) 855-2090

12–15
Symposium: Dry SO_2 Control
San Diego, California
Contact: Michael McElroy (415) 855-2471

Dwain Spencer, Vice President

COST ESTIMATES FOR LARGE WIND TURBINES

Wind turbine assessment has been the subject of much EPRI research. Wind turbines ranging from 50 to 250 kW dot numerous hillsides across the United States. In general, nonutility companies own these machines and sell electricity to local utilities. Few realistic assessments of wind turbine cost and performance in producing bulk power for the utility market exist. Many utilities perceive wind as an environmentally acceptable future generating option, but they lack the facts necessary for determining whether this technology is economically feasible. EPRI's current research attempts to provide sound cost and performance data for utility decision making.

EPRI selected Bechtel Group, Inc., to develop cost estimates for large wind machines. The principal objective was to estimate all direct and indirect engineering, procurement, and installation costs for wind turbine power plants as if the plants were to be owned and operated by a utility.

The study developed several scenarios, including baseline and alternative sites for installation, single-machine power plants and wind farms, and assumptions about industrywide wind machine production rates.

The MOD-2 and WTS-4 machines were selected for analysis on the basis of the apparent maturity of the technology and the availability of a technical data base. NASA, Lewis Research Center generously provided reports, MOD-2 design drawings, and specifications. Pacific Gas and Electric Co. made available its design specifications, and Hamilton Standard provided details on its Medicine Bow machine.

Bechtel used actual wind data from instrumented sites to avoid errors introduced by standard wind frequency distributions. Amarillo, Texas, was selected as the baseline site because it represents a "typical" wind resource. San Gorgonio, California, and Holyoke, Massachusetts, are more favorable and less favorable sites, respectively, than the baseline site. Table 1 gives wind characteristics at each site.

It might be mentioned here that wind data from candidate sites should be gathered for a period of several years. Average wind power (W/m^2) is a more meaningful measure of a site's wind energy than is average wind speed. The average power law coefficient describes the variation of wind velocity with elevation. It is preferably derived from short-time-interval data at sites with instrumentation at two or more levels. It has been observed that some sites have negative coefficients.

Study assumptions

Numerous assumptions were made for this study and are detailed in the complete report (AP-3276). The contractor used the best information available in 1981–1982. The resulting cost and performance estimates are equivalent to those of a conceptual design; the estimates are not suitable for design-for-construction purposes. This type of estimate is also suitable for comparing technologies in such activities as R&D budget planning.

A limited data base for wind turbine cost and performance currently exists. The study estimated capital costs on the basis of an assumption about the technology's maturity, which was determined by applying contingency factors. Future design changes and refinements attributed to the operating experience of prototypes in the field are purposely not accounted for in these cost estimates.

A computer model was used to estimate the performance of wind turbine arrays. This model has not been verified by field data

Table 1
GENERAL WIND REGIME CHARACTERISTICS

	Amarillo, Texas	Holyoke, Massachusetts	San Gorgonio, California
Location	35° 17′N 101° 45′W	42° 15′N 72° 38′W	33° 56′N 116° 34′W
Ground elevation (m)	1091	372	329
Mean air density (kg/m^3)	1.101	1.182	1.187
Average wind speed at 45-m elevation (m/s; mph)	8.4; 18.7	6.5; 14.4	8.1; 18.0
Average wind power at 45-m elevation (W/m^2)*	497	244	764
Average power law coefficient	0.19	0.25	0.12
Year	1979–1980 (average)	1979	1980

*Average wind power is defined as $P = \frac{1}{2}\rho \sum_{i=1}^{n} V_i^3$

where P = average wind power (W/m^2); ρ = density of air at site elevation and average temperature (kg/m^3); V_i = wind speed over the observation period (m/s); and n = number of observation periods over the year. Because average wind power is calculated from instantaneous wind speed raised to the third power, it cannot be directly related to the average wind speed shown above.

from full-scale machines. EPRI, DOE, and others are sponsoring ongoing research, including performance analysis for wind turbines and the development of appropriate dynamic control algorithms.

The study expresses all capital and operating cost estimates in constant mid-1982 dollars, with no escalation, and uses construction wage rates and labor productivities representative of the several sites. The power plant is assumed to be owned and operated by an investor-owned utility. The levelized fixed-charge rate is 16%/yr, based on an 8% investment tax credit, tax depreciation appropriate to the accelerated cost recovery system method, an 8.5%/yr general inflation rate over the 30-year plant book life, and project financing consistent with that recommended by the EPRI *Technical Assessment Guide* (P-2410-SR, May 1982).

Results

Table 2 presents the results of the 12 cases analyzed. The capacity factors were derived from computer simulations of machine performance, using wind resource data from instrumented sites. Table 3 gives additional details for Cases A and B. Single wind turbine power plants and wind farms (using 25 turbines) were analyzed at the Amarillo site for both 2.5-MW and 4.0-MW machines. Single-turbine plants were analyzed for the Holyoke and San Gorgonio sites. In addition, the study developed several cases to determine the effect of mass production on wind turbine costs.

Total capital requirements (plant facilities investment, land, organization and startup costs, working capital, royalties, and allowance for funds during construction) for single-turbine power plants range from about $3000/kW to $4800/kW, depending on assumptions. For the same type of machine and production methods, a wind farm costs 17–27% less to install on a $/kW basis than does a single machine. Capital costs between sites vary from 2 to 3%.

These capital cost estimates were compared with other estimates published by NASA, Lewis Research Center; Boeing; Hamilton Standard; and DOI. The published costs are lower than those developed in this study, principally because of differences in contingency, production rate, and mass production assumptions. Published data sources do not now permit a more definitive comparison (e.g., comparing capital costs on a section-by-section basis). However, Bechtel attempted to adjust the published capital cost data to the same base used in this study. This adjustment brought the results surprisingly close together.

Using operating and maintenance cost estimates developed in the study and the revenue requirements methodology described in EPRI's *Technical Assessment Guide,* Bechtel levelized revenue requirements (i.e., those that, if held constant over the project lifetime, would yield the same discounted cash flow return as the varying year-to-year revenue requirements) for electricity sales for the 12 cases (Table 2). The following observations are noted.

- Differences in levelized revenue requirements between 2.5- and 4.0-MW machines are generally 2–8%. Given the lack of long-term cost-estimating experience with these types of power plants, such differences are not considered significant.
- For the same machine design at the same site, wind farms consistently produce lower-cost electricity than do single machines. Wake shadowing and interference effects degrade wind farm performance slightly at a given site compared with single-machine power plants. However, the farms' lower total capital requirement (in $/kW) outweighs the performance penalty effect in terms of its impact on revenue requirements.
- Levelized revenue requirements vary widely (±30%) for the same size machine installed at the three sites (Amarillo, Holyoke, and San Gorgonio). This finding illustrates the advantage of installing a wind machine in a good wind resource (e.g., San Gorgonio's average wind power of 764 W/m^2) rather than in a poor wind resource (e.g., Holyoke's wind power of 244 W/m^2).

Table 2
ESTIMATED LEVELIZED REVENUE REQUIREMENTS FOR ALL CASES (A–L)

	Amarillo, Texas								Holyoke, Massachusetts		San Gorgonio, California	
	A	B	C	D	E	F	G	H	I	J	K	L
Machine (MOD-2 or WTS-4)	2	4	2	4	2	4	2	4	2	4	2	4
Number of machines	1	1	25	25	1	1	25	25	1	1	1	1
Power plant rating (MW)	2.5	4.0	62.5	100	2.5	4.0	62.5	100	2.5	4.0	2.5	4.0
Wind machine production rate	—[1]	—[1]	—[1]	—[1]	—[2]	—[2]	—[2]	—[2]	—[1]	—[1]	—[1]	—[1]
Capacity factor (%)	26.4	18.9	24.7	17.6	26.4	18.9	24.7	17.6	19.1	14.8	35.0	29.1
Total capital requirement ($/kW)[3]	4775	3703	3496	2700	3978	3004	3233	2497	4717	3610	4865	3775
Levelized revenue requirements for investor-owned utility (mills/kWh; constant mid-1982 dollars)[4]	168.5	182.1	127.1	136.0	142.8	150.1	118.1	126.4	225.7	223.4	132.6	123.4

[1]Nominal.
[2]High volume.
[3]Includes plant facilities investment, land, allowance for funds during construction, organization and startup expenses, and working capital.
[4]Levelized, using before-tax average cost of money (3.76%/yr in constant dollars).

Table 3
SINGLE WIND TURBINE TOTAL CAPITAL REQUIREMENT
(existing production methods)[1]

	2.5 MW (Case A)		4.0 MW (Case B)	
	$/kW	%	$/kW	%
Rotor	1238	26	728	20
Nacelle[2]	2166	45	2016	55
Tower	506	11	389	10
Ground support	91	2	51	1
Balance of plant	352	7	219	6
Other[3]	422	9	300	8
Total	4775	100	3703	100

[1]Constant mid-1982 dollars, including contingencies.
[2]Includes the drive train, gear box, and lubrication and hydraulic systems.
[3]Land, organization and startup costs, royalties, working capital, and allowance for funds during construction.

Because capital cost differences were observed to vary by only 2–3% for different locations, location performance differences far outweigh capital cost differences in terms of impact on levelized revenue requirements.

When electricity costs from 2.5-MW and 4.0-MW turbines are compared with those anticipated from utility-scale peaking and cycling equipment (e.g., natural gas– or fuel oil–fired combustion turbines or combined cycles), certain observations can be made concerning the conditions necessary for cost competitiveness.

- Future gas or oil prices have to escalate at average real (above general inflation) rates in excess of 3%/yr.
- Significant capital cost reductions must be realized. The estimated range is 30–50% reductions in the capital cost of 2.5-MW and 4.0-MW machines.
- Performance improvements for any given machine (through design changes, better siting, or other means) must be realized.

The 2.5-MW and 4.0-MW machines currently deployed in the field are generally considered precommercial. The economics developed for this study show that the R&D for large, horizontal-axis machines is far from complete. New designs and construction materials should be developed to bring costs down. There are indications that the cost of smaller (200–300 kW) horizontal-axis machines may be less on a $/kW basis than the cost of large horizontal-axis machines. EPRI plans to gather performance data from machines already installed in the field and to conduct periodic cost evaluations of promising concepts, including smaller horizontal-axis machines. *Project Manager: S. M. Kohan*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

AQUEOUS DISCHARGE MONITORING AND TREATMENT

As the concentrations to which waterborne contaminants can be controlled approach the levels specified in ambient water quality criteria, treating power plant discharge streams—or even reliably detecting the pollutants—becomes difficult, costly, and uncertain. An important result of recent work in EPRI's water quality control subprogram has been to establish a sound scientific basis for defining the precision, bias, and detection limits of analytic methods commonly used to monitor waterborne pollutants of interest to the utility industry. For cases that require the removal of trace metals from plant discharges, laboratory work has demonstrated the technical performance of a chemical treatment based on the adsorption of the elements onto iron hydroxide precipitate. Engineering studies examining the application of this method to power plant discharges have projected significant cost savings over conventional processes.

In implementing the Clean Water Act, the Environmental Protection Agency (EPA) has stipulated effluent limitation guidelines based on water quality for the steam-electric utility industry. It instituted the National Pollutant Discharge Elimination System (NPDES), which requires all publicly and privately owned domestic steam-electric power plants to obtain permits to discharge wastewaters. This system, together with the promulgation of National Ambient Water Quality Criteria and Safe Drinking Water Standards, has intensified utility concern about monitoring and controlling plant discharge streams. To help utilities comply with discharge requirements, EPRI is sponsoring two research projects, RP1851 and RP910, which address effluent monitoring and control, respectively.

Discharge monitoring

Because pollutant detection and measurement are necessary for determining discharge permit compliance, the importance of clearly defined and well-understood sampling and analytic methods is obvious. However, the monitoring methods and procedures specified for utility pollutants can often yield uncertain results. Pollutants may be present in waste streams in trace amounts (i.e., at $\mu g/L$ levels), the detection of which demands increasingly sensitive analytic methods and instrumentation. Current monitoring requirements have pushed the use of such techniques as atomic absorption spectroscopy and combined gas chromatography–mass spectrometry to the limits of current science.

The ultimate objective of RP1851 is to furnish the utility industry with an improved capability for monitoring plant waste streams. To achieve this EPRI and the contractor, TRW, Inc., outlined three major tasks: characterizing utility aqueous discharges, establishing the precision and accuracy of selected sampling and analytic methods for specific pollutants, and improving these techniques to make them simpler and less expensive.

Effluent characterization Efforts to identify waste stream constituents of greatest concern to the utility industry began with EPA's current list of 126 priority pollutants, 5 conventional pollutants, and 54 nonconventional pollutants (categories defined by the 1977 Clean Water Act Amendments). To characterize the industry's aqueous discharges, TRW collected and computerized effluent data for the listed pollutants from the open literature, from a random selection of utility plant NPDES permit applications, and from EPA and Edison Electric Institute data bases.

The resulting data set was carefully screened to identify and rank pollutants of interest for future research. The screening process involved four criteria.

- The average concentration of the pollutant of interest must exceed 100 times the most stringent federal water quality standard for that pollutant.
- 15% of the concentration data must exceed 100 times the most stringent federal water quality standard.
- There must be more than 10 data points for the pollutant from the NPDES permit applications and more than 5 from the open literature.
- In 15% of the documented occurrences of the pollutant, the flow-weighted average discharge concentration must exceed the intake concentration (taking into account a factor for measurement uncertainty).

Pollutants satisfying these criteria were ranked according to the ratio of their flow-weighted average discharge concentration to 100 times the most stringent federal water quality standard. This industry effluent data characterization effort yielded the following results.

- The pollutants of interest to the utility industry are 11 trace metals (arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, nickel, selenium, and zinc), total residual chlorine, phosphorus, sulfate, and ammonia.
- Of the 11 trace metals identified, all except iron and manganese are designated by EPA as priority pollutants. When flow-weighted averages from the utility effluent data were compared with federal water quality criteria for all the EPA trace metal priority pollutants (Figure 1), several metals were found to exceed the specified concentrations. (The federal criteria are guidelines, and a few states have begun to incorporate parts of them into discharge permits. Discharges from a power plant are governed by the plant's NPDES permit.)
- Arsenic, beryllium, cadmium, lead, and selenium are present in coal and thus are prominent in the discharges of coal-fired power plants. Cadmium is prominent in oil-fired-plant discharges. As can be expected, discharges of these trace metals are not significant for gas-fired plants.
- Common in aqueous discharges for all fuel categories are chromium, copper, iron, manganese, nickel, zinc, total residual chlorine, phosphorus, ammonia, and sulfate. The

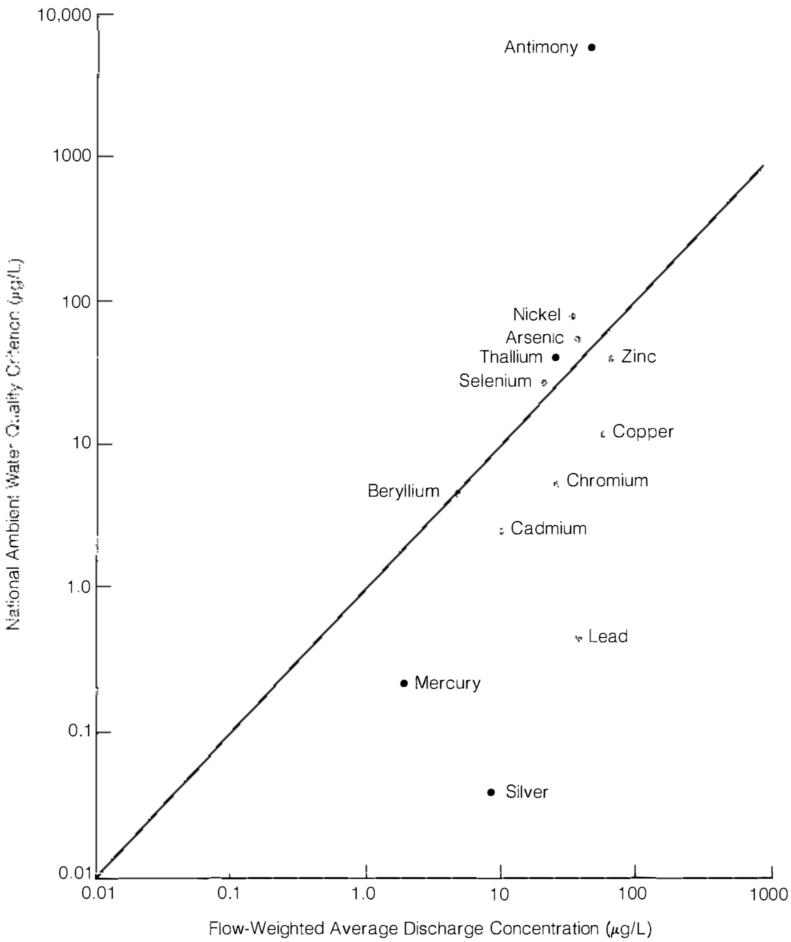


Figure 1 As part of an effort to characterize utility effluents (RP1851), selected data on non-cooling-water plant discharges were compared with National Ambient Water Quality Criteria for 13 trace metals designated by EPA as priority pollutants. The diagonal line represents discharge concentrations equal to the criteria; elements below the line are those whose discharge concentrations averaged across the utility industry exceed the federal criteria. The colored data points indicate the trace metals found by the RP1851 screening process to be among the pollutants of greatest concern to the utility industry.

presence of these substances can be attributed to material corrosion or to the use of chemical additives for water treatment.

□ Data are inadequate to confirm the presence of any organics in aqueous plant discharges, at least at concentrations that would be of concern.

□ Differences in the amount of pollutants discharged from the various plants were quite dramatic. Even similar wastewater streams within a particular fuel category showed large differences. Hence it is impossible to make broad, industrywide generalizations about effluent characteristics.

Methods assessment After identifying the priority pollutant trace metals as the dominant class of effluent constituents, TRW next evaluated the available precision and bias statistics for EPA-approved or equivalent procedures for measuring trace metals. In the context of chemical analysis and instrumental measurement, precision refers to the reproducibility of results; high reproducibility indicates a low level of random errors and thus high precision. Bias refers to the accuracy with which the method of measurement arrives at the true value; a high bias means poor accuracy. High bias may be the result of systematic errors caused by faulty procedures, varying reagent quality, or instrumental artifacts.

The measurement methods studied were flame atomic absorption spectroscopy (AAS), graphite-furnace AAS, inductively coupled argon plasma (ICAP) AAS, cold-vapor AAS, and gaseous-hydride AAS. The first three methods are used for detecting all 13 EPA priority pollutant trace metals, while cold-vapor AAS is generally considered acceptable for measuring mercury and gaseous-hydride AAS for antimony, arsenic, and selenium.

To evaluate the precision and bias of each method, TRW reviewed and collated data from several sources. One source was the 1980–1981 study of EPA's Discharge Monitoring Report/Quality Assurance (DMR/QA) Program, which is responsible for evaluating the self-monitoring capability of NPDES permit holders. (The program does this by sending samples to each permit holder for analysis, then checking the reported results.) Other data sources were a monitoring study by EPA's Effluent Guidelines Division, a study of analytic methods by the Utility Water Act Group, and various analytic procedures manuals from EPA, the U.S. Geological Survey, and the American Society for Testing and Materials.

For each method TRW determined overall levels of precision and the method's limit of detection (LOD), which measures its sensitivity in detecting and identifying an element. This work offers a perspective on the industry's ability to meet federal performance standards. The major findings are as follows.

□ An analysis of the DMR/QA data from all industries for both flame AAS and graphite-furnace AAS revealed the overall precision to be worse than that of EPA's controlled laboratory results by nearly a factor of two.

□ For some trace metals, the DMR/QA sample concentrations were as high as five times the flow-weighted average concentrations of power plant discharges.

□ Although data from available validation studies on flame AAS generally support the EPA-quoted LODs, limited data on both ICAP and graphite-furnace AAS suggest there is some difficulty in achieving EPA-quoted LODs with these methods.

□ According to LODs calculated from the overall precision data, graphite-furnace AAS can reliably detect antimony, arsenic, chromium, copper, nickel, and zinc at the concentrations specified in National Ambient Water Quality Criteria; gaseous-hydride AAS can detect antimony, arsenic, and selenium;

and ICAP AAS can detect cadmium, chromium, copper, lead, selenium, and zinc.

The results of the precision and bias data review will be incorporated into a preliminary reference guide on the sampling and analysis of selected trace metals. Rather than detailing the specific procedures, the document will compile all available information on their capabilities, limitations, and applications. It will include references to sources describing the procedures, as well as a discussion of simplified or more economical techniques.

In addition to the preliminary guide on trace metals sampling and analysis, two other RP1851 reports will be available this summer: one on the utility effluent data analysis and one on the trace metals analytic methods statistical review. All three reports will be helpful to utilities, architect-engineers, and government agencies in judging the validity and usefulness of aqueous trace element data, in establishing reasonable effluent criteria, and in determining levels of plant discharge compliance.

An example of a case where such information could be useful is the state of Pennsylvania's attempt to enforce plant discharge concentrations for arsenic at about 0.0022 μg/L. Another example involves Virginia, where a mercury discharge limit of 0.05 μg/L is being discussed. EPA's quoted detection limit for both arsenic and mercury as measured by graphite-furnace AAS is 0.3 μg/L. Further, the EPRI analytic methods statistical review yielded LODs of 14 μg/L for arsenic and 0.4 μg/L for mercury with graphite-furnace AAS. Such results stress the need to clearly define the performance of analytic methods. Discrepancies between effluent limits and monitoring capabilities have created confusion and concern among utilities.

The EPRI effort has been expanded to include a measurement precision and bias review for six substances in EPA's conventional and nonconventional pollutant categories—iron, manganese, total suspended solids, oil and grease, total residual chlorine, and ammonia—and the preparation of a preliminary reference guide on the sampling and analysis of these substances. Also being undertaken are comprehensive interlaboratory field qualification studies at volunteer utility laboratories to develop industry-specific statistics on analytic methods for substances of interest to utilities. Participants are being sought for the field studies, which are scheduled to begin late this summer. Other future work will address the technical issues associated with wastewater sampling and the development of simplified, more economical sampling and analytic methods.

Effluent treatment

To satisfy regulatory requirements, some plants must consider design modifications to reduce or eliminate specific pollutant emissions. One option is to chemically remove the target trace constituent from the aqueous process stream. RP910 has developed a novel chemical treatment process for removing trace elements from utility wastewaters. This process entails the physical adsorption of aqueous trace elements onto iron hydroxide precipitate in a reaction-contact system.

Early laboratory studies of the process by Stanford University (EPRI CS-1573) demonstrated removal efficiencies of over 90% for several trace elements at low initial concentrations. One exception was wastewater bearing chelating agents, such as EDTA (ethylenediaminetetraacetic acid). Elements examined in the initial study were arsenic, cadmium, chromium, copper, lead, selenium, and zinc.

The laboratory studies were expanded to include vanadium, nickel, boron, and species of selenium and arsenic. Removal efficiency varied with the oxidation states of selenium and arsenic; whereas reductions of over 85% were achieved for arsenate and selenite and over 50% for arsenite, the results for selenate were poor. The process did not affect boron at all, but it yielded excellent removal efficiencies (over 90%) for vanadium and nickel. Figure 2 shows the projected effects of iron adsorption treatment on selected trace metals, given the initial concentrations presented in Figure 1.

This new technology can employ conventional hardware, as confirmed in engineering and economic feasibility studies by Brown & Caldwell. Options include using conventional mechanical processing equipment for solid-liquid reaction and separation (e.g., solids-contact or sludge-blanket water treatment clarifiers and mixed-media filters); treating plant wastewater effluent in a separate reaction and sedimentation basin or pond; and treating the process wastewater as it is discharged into an existing basin or

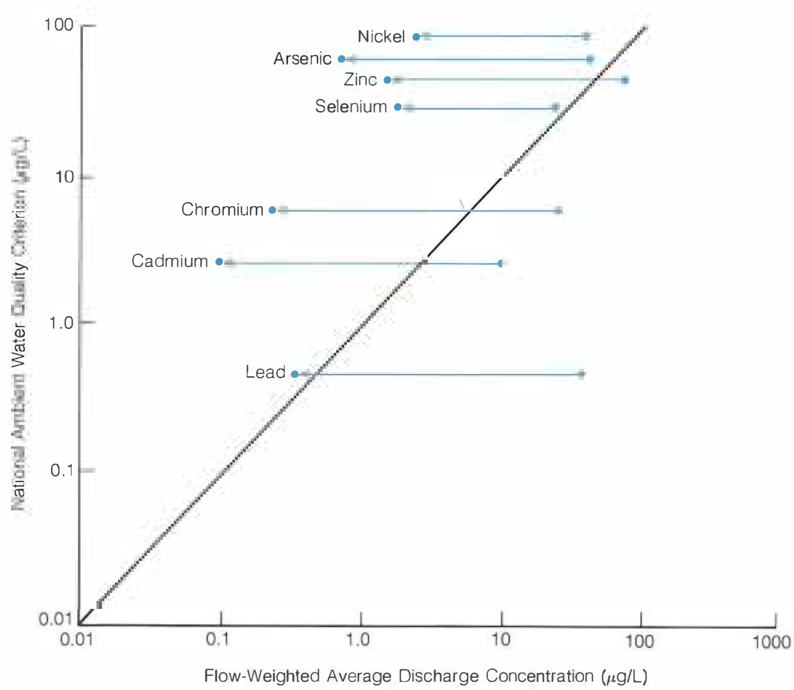


Figure 2 Projected effects of applying the iron adsorption process to selected trace metals at initial concentrations based on the plant discharge data analysis conducted under RP1851. The results of laboratory testing were extrapolated to yield these projections, which suggest that the process can reduce these trace elements to levels satisfying National Ambient Water Quality Criteria.

pond. Figure 3 illustrates these options.

To compare the treatment costs for these options, order-of-magnitude estimates were developed for a plant with a peak effluent flow of 14,000 gal/min (0.88 m^3/s) and an average flow of 7000 gal/min (0.44 m^3/s). For 90% removal of total arsenic, the estimated treatment costs per million gallons were $144 for the existing-pond option, $191 for the separate-pond option, and $328 for the mechanical processing option. A comparison of the iron adsorption technique with other, state-of-the-art treatment methods indicates its economic advantage. For instance, compared with conventional chemical lime coprecipitation for arsenic removal, iron adsorption using mechanical processing equipment offers an estimated cost savings of $216 per million gallons, or nearly 40%.

The prospects for the commercialization of the iron adsorption process are excellent. Given the promising results to date, the next step is to demonstrate the process under actual plant operating conditions to confirm the laboratory performance data and verify the technical and economic advantages. Field-test plans call for a host utility plant having ash ponds with selenium or arsenic and site conditions that are conducive to demonstrating one of the pond treatment options. The tests are scheduled to begin this spring, and results are expected by early 1985. *Project Manager: Winston Chow*

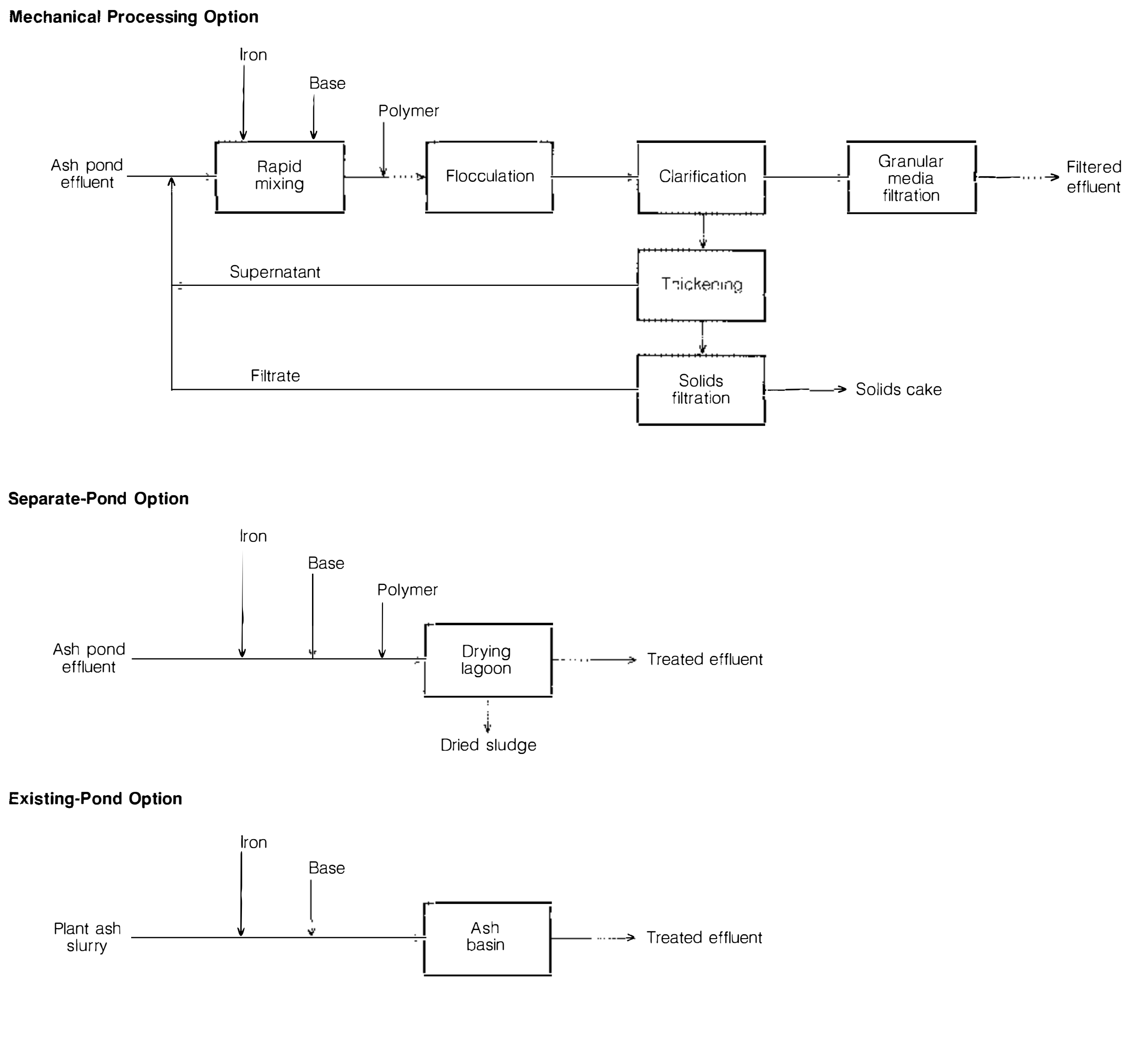


Figure 3 Three proposed process options for applying iron adsorption to the removal of trace elements from power plant aqueous discharges. The first option uses conventional mechanical processing equipment; the second requires a new, separate sedimentation pond at the power plant site to treat the discharge; and the third uses an existing ash basin.

SPRAY-DRYING FGD

Utility interest in spray drying for SO_2 and particulate control has increased in response to vendor claims for the process (easy-to-handle dry wastes, simplicity, lower costs and energy requirements) and to federal SO_2 removal requirements for low-sulfur coals (70%, compared with 90% for high-sulfur coals). Unfortunately, limited data are available for utilities to use in process evaluations before commercial commitment and in efforts to improve the cost and reliability of this potentially important flue gas desulfurization (FGD) option. Under RP1870 EPRI is sponsoring pilot- and full-scale testing to develop the information required for system design and optimization in order to ensure reliable utility operation at minimum cost.

The utility industry has recently made a large commitment to spray-drying FGD systems. The total capacity of the systems contracted to date is approximately 6800 MW, or 6.5% of the U.S. coal-fired generating capacity committed to FGD. This commitment to dry scrubbers is unusual, considering that the contracts were awarded before any commercial systems were operational at utility power plants. However, the technology may offer significant advantages if it proves to be applicable.

The use of spray dryers for FGD represents a new application of an old technology. In this case the concern is not just with drying a product but also with absorbing SO_2. Typically in FGD applications, a slurry of water and lime is sprayed through an atomizing device, usually a rotary atomizer, into a drying vessel. Flue gas is introduced cocurrently with the atomized slurry, and SO_2 is absorbed into the slurry as the slurry droplets dry. The dry product leaves the bottom of the drying vessel and is fed into a particulate collection device, either a baghouse or an electrostatic precipitator (ESP). Some of this product is usually reslurried and recycled to the spray dryer to increase SO_2 removal and minimize the lime requirement.

Promise and uncertainties

Spray drying has several potential advantages over conventional wet scrubbing. The dry product is easier to handle during disposal, and when water is added, the solids undergo a cementlike reaction to form a material that is claimed to be suitable for landfill and capable of preventing significant leaching. Also, because not enough water is added in the spray dryer to saturate the flue gas, the exit gas should not have to be reheated to prevent condensation. (The heat rate penalty for flue gas reheating is approximately 200 Btu/kWh, which can represent the largest single energy requirement of an FGD system.) Finally, the spray-drying system envisioned by suppliers is simpler and uses less expensive materials than a wet scrubber. These two factors would lead to lower capital costs and lower maintenance and energy requirements.

None of these claimed advantages has been verified at commercial scale, however, and there are several other uncertainties regarding application of the technology. These include control of the spray dryer exit gas temperature to prevent wet solids from entering the particulate collection device; quantification of SO_2 removal in the baghouse; effects of solids recycling on alkali utilization; and alkali requirements for a given level of SO_2 removal. There are also questions about the integration of the spray dryer and the baghouse, which is the preferred particulate collection device. No work to understand their interactions, much less to quantify or optimize them, has been reported. Two development areas for existing baghouses are how to control pressure drop across the bags and how to select the optimal cleaning cycle. The importance of these questions for a spray dryer–baghouse combination is not known. The other particulate option, an ESP, may experience problems if solids from the spray dryer are wet and form a coating on the ESP plates.

EPRI has initiated both pilot- and full-scale efforts to resolve these questions. The results of the testing are providing a clearer picture of the technology. Current EPRI spray-drying work consists of three projects: testing at a 2.5-MW pilot plant at the Institute's Arapahoe Test Facility (RP1870-3), an evaluation of waste from vendor pilot plants to provide data for comparison with the EPRI pilot plant data (RP1870-2; CS-2766), and a field evaluation of a full-scale system (RP1870-4).

Pilot testing

Data collected at Arapahoe have shown that the percentage of solids in the slurry fed to the atomizer significantly affects drying—and hence the buildup of moist reaction products on the walls of the spray dryer. Also, insulating the baghouse has been found to be important in preventing corrosion on its walls.

Table 1 shows how certain operating conditions affect the feed slurry's solids content and how that in turn affects the dryness of the material collected at the bottom of the spray-drying vessel. Once-through operation at a low inlet SO_2 concentration resulted in the lowest amount of solids in the slurry fed to the atomizer. It was at these conditions that problems with wet spray dryer products persisted. Operating modes that resulted in a higher slurry solids content (i.e., a higher inlet SO_2 concentration and/or solids recycle) greatly improved the operation of the spray dryer at short vessel residence times.

The variables found to have significant impact on SO_2 removal are solids recycle, makeup water quality, and a temperature parameter called the approach to saturation (which is the difference between the temperature of the spray dryer exit gas and the gas's saturation temperature). Figure 4 illustrates the effects of solids recycle by comparing test results for once-through operation with results from tests in which solids were recycled at a 2:1 ratio (by weight) to reagent added. Both test series featured an

Table 1
SLURRY SOLIDS CONTENT AT VARIOUS OPERATING CONDITIONS

Operating Mode*	Nominal Inlet SO_2 (ppm)	Solids in Slurry Feed (wt%)	Vessel Residence Time (s)	Nature of Spray Dryer Product
Once-through	350	3–7	7	Wet
Once-through	1000	12–16	7	Dry
Recycle (2:1)	350	6–16	7	Dry
Recycle (6:1–8:1)	350	17–24	7	Dry
Recycle (12:1)	350	31–37	5	Dry

*The recycle ratios represent pounds of solids recycled per pound of dry calcium hydroxide added.

Figure 4 Effects of solids recycle and baghouse SO_2 removal on spray-drying FGD system performance. The colored curves are best-fit curves for the results from pilot tests with recycle (2:1 recycle ratio); the data points are the results from tests under similar conditions but with once-through operation. Clearly, solids recycle improved spray dryer and total system SO_2 removal. The test data also reveal the baghouse's important contribution to overall system performance at high SO_2 removal levels.

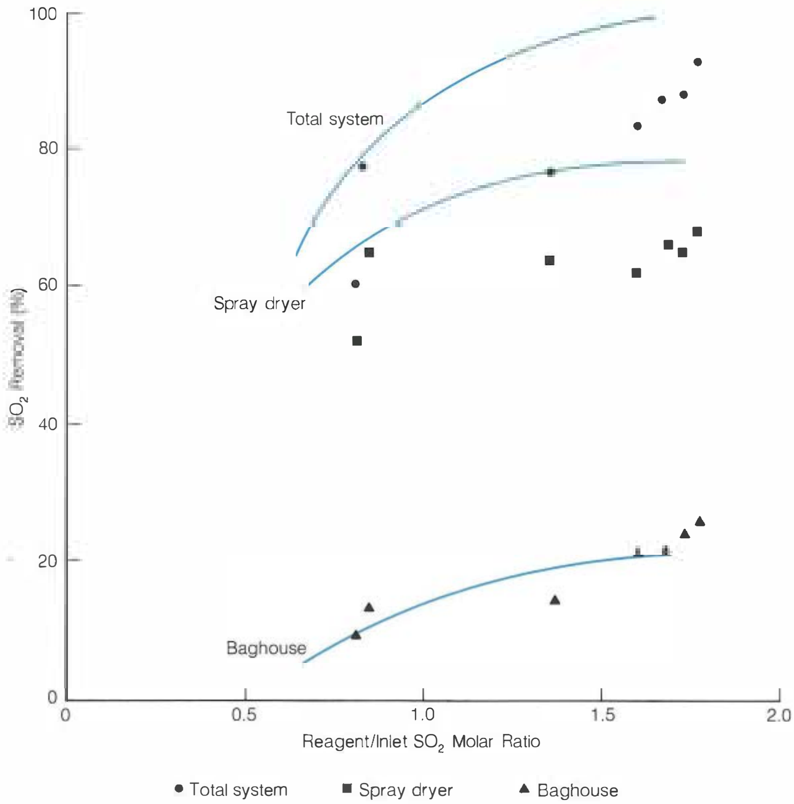


Table 2
FULL-SCALE SPRAY-DRYING TESTS: PRELIMINARY SO_2 REMOVAL RESULTS

Coal	Reagent Ratio	Recycle Ratio	SO_2 Removal (%)		
			Nominal	Spray Dryer	Baghouse
Low sulfur	0.6–0.7	11:1–14:1	75	67–69	7–9
Low sulfur	0.7–0.8	9:1–13:1	90	80–81	9–10
High sulfur	1.3–1.4	2:1–3:1	90	75–77	13–15
High sulfur[a]	0.9–1.1	3:1–4:1	90	67–69	22–24

Note: The reagent ratio is the molar ratio of reagent (calcium hydroxide) to inlet SO_2. The recycle ratio is the ratio by weight of solids recycled to reagent added.

[a]In these tests calcium chloride was added to produce high chloride concentrations.

inlet SO_2 concentration of 400 ppm and a 20°F (11°C) approach to saturation. Note that system SO_2 removal without recycle is lower mainly because of reduced removal in the spray dryer.

The pilot testing has also demonstrated that SO_2 removal in the baghouse is critical for achieving an overall system removal efficiency of greater than about 80%. Figure 4 indicates the importance of the additional SO_2 removal that occurs when flue gas contacts unreacted reagent in the baghouse. The recycle test data (colored curves) show a maximum SO_2 removal of slightly less than 80% for the spray dryer. However, enough SO_2 was removed in the baghouse to increase the overall system performance to better than 90%.

Full-scale testing

The objective of this effort was to acquire performance data from an operating, utility-scale spray dryer FGD system. The work focused on SO_2 and particulate removal efficiency and lime reagent consumption. The system evaluated—a demonstration unit supplied by Joy Manufacturing Co. (Western Precipitation Division) and Niro Atomizer, Inc.—is located at Northern States Power Co.'s Riverside station in Minneapolis. This system was chosen because it is the first lime-based system in operation that uses a full-size spray dryer module (46 ft, or 14 m, in diameter). The testing was conducted on flue gas from both low-sulfur and high-sulfur coals.

Preliminary results from the field tests are shown in Table 2. The system results for low-sulfur operation compare well with those from the EPRI pilot plant tests. However, there is a difference in the relative contributions of the spray dryer and the baghouse to SO_2 removal. At Riverside the spray dryer is responsible for a greater proportion of the total system SO_2 removal. A possible reason is the full-scale unit's higher inlet flue gas temperature, which requires that more water be added in order to reach the same outlet temperature. Because this increased amount of water takes longer to dry, there is more time for SO_2 absorption in the spray-drying vessel.

Although the tests were short term, the high-sulfur results for the Riverside unit indicate that 90% removal can be achieved at moderate levels of reagent use. It was also found that these levels can be reduced by adding calcium chloride to the feed slurry. These results justify a more comprehensive evaluation of the applicability of the technology to high-sulfur coals. *Project Manager: Richard Rhudy*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Vice President

DISTRIBUTION

Maximum pulling lengths for URD cable

Determining the maximum safe pulling lengths for power and control cables is essential for designing the most cost-effective, reliable cable system because this information will reduce the number of cable splices and splice enclosures. Cable splices are considered to be less reliable than factory-produced cable, so reducing the number of cable splices results in a more reliable cable system.

Theoretical methods for calculating the pulling tensions and sidewall pressures to be expected in pulling cable through a duct were established over 30 years ago. At that time many of the variable factors that influence these calculations were not well known because of the lack of adequate test data; therefore, safety factors were overly conservative.

The objectives of this research project were to determine and quantify the factors that influence the lengths of 600-V, 15-kV–138-kV cables that can be pulled through duct structures without damaging the cable, and to develop comprehensive guidelines to calculate safe pulling lengths for the various cable designs and conditions that are likely to be encountered in practice (RP1519).

The findings of this research are both numerous and important. Of particular interest is the conclusion that compression-type pulling eyes customarily employed with aluminum conductor cables significantly limit maximum pulling tensions and hence cable lengths. Increases in pulling tensions on the order of 40–50% can be achieved by using epoxy-filled pulling eyes.

Literature searches made during the course of this project indicated that calculation values in current use are too conservative when applied to cables of modern construction and materials. One of the most significant limiting values that affect a cable pull is sidewall bearing pressure. Literature searches produced values from as low as 150 lb/ft (223 kg/m) to as high as 400 lb/ft (595 kg/m). Laboratory and field tests proved these values to be conservative by factors of 6–10.

A computer program (CABLPUL) was developed as part of this project to aid the engineer in lengthy cable-pulling calculations. *Project Manager: T. J. Kendrew*

TRANSMISSION SUBSTATIONS

Detection of PCBs in transformer oils

Askarel is a generic term for a group of nonflammable synthetic chlorinated hydrocarbons used as electrical insulating fluids in transformers and capacitors. Most contain polychlorinated biphenyls (PCBs). PCBs have been judged to be harmful in the environment, and their manufacture, use, and disposal have been subject to government regulation since 1978. This regulation extends not only to askarel-filled transformers containing PCBs but also to the much larger number of mineral-oil-filled transformers, which may have been contaminated with PCBs during manufacture or service.

Oils containing less than 50 ppm of PCBs when taken from transformers are defined as non-PCB liquids and have no unusual limitations on their handling and disposal (except that oils with any detectable PCBs may not be used in applications involving wide dispersal, such as dust control). Oils with PCB concentrations of 50–500 ppm are considered contaminated, and those with concentrations above 500 ppm are considered to be totally PCB liquids; the handling and disposal of oils in these categories require special techniques.

Ultimately, each of the 20 million oil-filled transformers now in service in the utility industry must be tested for its PCB content. While there are adequate analytic methods for determining an oil's PCB content in the laboratory, this process is time-consuming and expensive. Samples must be packed and sent to the laboratory for analysis. In response to the need for a simpler procedure, EPRI initiated a comprehensive program to develop techniques for measuring PCBs in transformer mineral oils in the field.

A number of instrumental approaches were evaluated. The most promising for immediate field use proved to be X-ray emission with the MESA-200 analyzer of Horiba Instruments, Inc. A report on field experience with this instrument, which measures an oil's chlorine content, appeared in the July/August 1982 *EPRI Journal* (p. 42). Since then many utilities have purchased the analyzer and are satisfied with this test method.

Because the initial cost of such an instrument is high (about $25,000), EPRI continued efforts to develop a smaller, disposable means of testing transformer oils for their chlorine content. This has led to the Clor-N-Oil PCB Screening Kit, which is designed to determine if oil samples have less than 20 ppm of chlorine. The test philosophy—similar to that for the Horiba instrument—is that any oil containing less than 20 ppm of chlorine cannot possibly contain 50 ppm (or more) of PCBs and therefore can be labeled a non-PCB liquid, requiring no further tests. Samples with more than 20 ppm of chlorine do not necessarily have a PCB concentration above 50 ppm; however, because this simple chlorine check does not indicate the quantitative PCB level, the remaining samples should be tested on a gas chromatography instrument. Use of the screening kit may eliminate half or more of the oil samples formerly requiring laboratory testing.

Each kit is individually packaged and contains premeasured reagents in sealed, crushable glass ampules, along with two polyethylene test tubes and a polyethylene pipette that is used to draw the oil sample (Figure 1). The ampules are broken sequentially to release the reagents in the sample; the final color of the solution indicates the presence or absence of chlorine. Any shade of blue or purple indicates that the oil contains less than 50 ppm of PCBs, and the transformer can be labeled non-PCB. If the resulting color is yellow, the oil needs further testing to determine the exact PCB content. After the test is complete and the results recorded, the entire kit is disposed of to avoid the contamination of future tests.

The highly portable Clor-N-Oil kit allows the user to screen out contaminated oils and avoid much gas chromatography testing, which is both slow and expensive. The test can be performed in a utility workshop by maintenance personnel or on site in the event of a spill or critical situation. Transformer oil can be tested with the kit for as little as $4 a sample. The kits have performed with good accuracy and consistency in the laboratory and in the field on a trial basis at 88 utilities. These kits are now commercially available from Dexsil Chemical Corp.

In a related project with Battelle, Columbus Laboratories (RP2131-1), a field-usable PCB detector is under development. Unlike the screening methods discussed above, this instrument should be able to quantitatively analyze oil samples and determine specific PCB content. This detection concept is based on infrared spectroscopy. As infrared radiation passes through the sample, it disperses into a spectrum, which is then analyzed. Each sample containing PCBs exhibits a distinctly characteristic peak that is proportional to the PCB content.

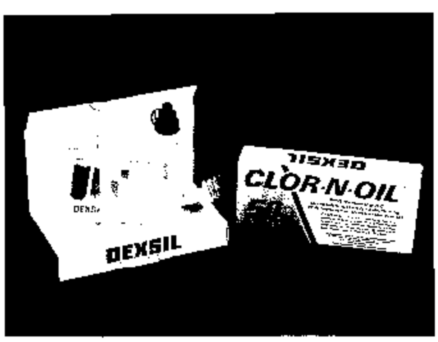


Figure 1 This compact, disposable Clor-N-Oil kit, developed under EPRI contract, can be used in the field to screen transformer oils for PCBs.

Figure 2 A researcher examines the results from an infrared detector (right). EPRI is developing a field-usable version of this instrument (to be packaged in a single unit) for detecting PCBs in transformer oil.

A Fourier transform infrared (FTIR) spectrometer has been chosen for this test method (Figure 2). The instrument is capable of optically analyzing a sample and carrying out the Fourier transformation rapidly through a built-in microprocessor-based computer. The total test takes only a few minutes.

Transportable FTIR spectrometers are commercially available. The key, however, lies in the development of a suitable protocol for sample preparation. Many constituents of transformer oils, such as aromatic components, interfere with the spectral peak resulting from the PCBs. Therefore, an automated solvent extraction process has been developed. The computer built into the instrument will control the solvent extraction process and then feed the treated oil sample into the detector for analysis. The PCB results will be printed out to give a permanent test record.

This field instrument is being designed for a throughput of one sample every five minutes once the instrument is set up. The first sample may take 10 to 15 minutes longer to test. Just as in the evaluation of the Horiba instrument, EPRI plans to equip a station wagon with the FTIR spectrometer and let member utilities test it in the field. It is expected to be ready for field tests by the second quarter of this year. *Project Manager: Vasu Tahiliani*

Substation control and protection systems

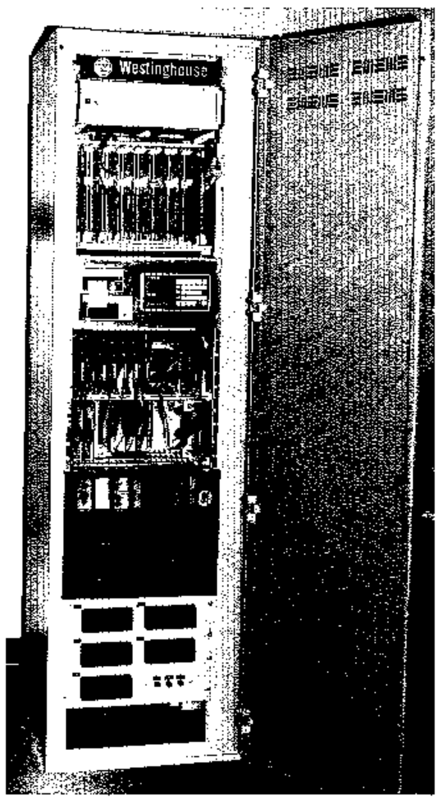
EPRI is sponsoring a project to develop a new substation control and protection system (RP1359). The goal is to achieve cost reductions and improved system performance through a distributed, microprocessor-based system. The microprocessor is a small, relatively low-cost component that could lead to a modular (therefore expandable) and easily maintained system.

There are several technical challenges in this project. At the outset, it was recognized that the system architecture selection was key to success of the project (*EPRI Journal*, January/February 1983, p. 33). The architecture had to meet the functional performance requirements in a way that provided the right amount of flexibility, as well as high reliability, at a competitive cost. The project also involved the management of significant development risks, which was accomplished by staging the development work in a manner that first addressed high-risk areas. This forced the adoption of a modular implementation strategy. The same philosophy is being pursued in the demonstration phase of the project, which has just begun.

The first units to be delivered are so-called stand-alone transmission line digital protective relay devices. (*Stand-alone* means the ability to function without peripheral support systems.) A prototype relay (Figure 3) was delivered early in December 1983 by General Electric Co. (RP1359-5). The unit was shipped to the host utility, Public Service Electric and Gas Co. of New Jersey, for installation in PSE&G's 500-kV Branchburg substation (RP1359-4). A similar relaying device by Westinghouse Electric Corp. (Figure 4) was scheduled for shipment in March 1984. In parallel with this, Westinghouse is building and testing a relatively complete system for control and protection of a substation to be delivered later in 1984 to PSE&G for installation in its Deans substation, which is connected to Branchburg by a 20-mi (30-km), 500-kV line. A second General Electric relaying terminal will also be a part of the Deans system. An expected benefit of this is that problems can be discovered early and (it is hoped) corrected without major expenditures.

The control and protection system architecture was selected with the assumption that fiber optic communication links would be used within substations so electronic equipment (which handles the encoding and decoding of data and commands to be transmitted through the fibers) can be placed close to the high-voltage equipment in the switchyard. Although this concept is not new, any such system will have to survive the high electromagnetic interference (EMI) levels of the switchyard.

Figure 4 A Westinghouse-built prototype transmission line digital protective relaying terminal set up for testing at Westinghouse. The terminal will be installed in PSE&G's Branchburg substation in the second quarter of 1984.



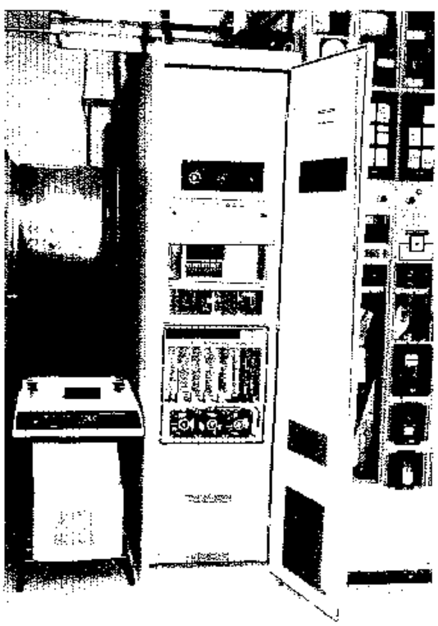


Figure 3 A prototype transmission line digital protective relaying terminal built by General Electric and installed for testing in PSE&G's Branchburg substation.

At the outset of the project, a significant effort was concentrated on EMI work by Texas A&M University (RP1359-2). A special truck-mounted measuring system was built. This system relies on instruments previously developed for military electromagnetic pulse measurements. It is capable of recording electric and magnetic field components from two sensors with two different time bases for each sensor so that both short and long impulses can be studied. The triggering of the data-capture window can be varied within a wide range, ensuring that the worst transient is captured. The instrument system can record transients with a frequency content in excess of 100 MHz.

The analysis of the data is now complete and has been published (EL-2982). The data have been used to formulate electromagnetic compatibility testing of the system modules to be placed outdoors in the substation switchyards. The instrumentation system has been transferred to BDM Corp., Albuquerque, New Mexico, and is available through BDM for use by utilities and others for R&D purposes.

This project is nearing the end of the development phase. Transfer of the technology to the utility industry is the next step. To accomplish this, an expanded demonstration of line protective relaying devices is planned in early 1985. Selection of participating utilities is in progress. *Project Manager: Stig L. Nilsson*

Amorphous metal for transformers

This project was initiated in 1978 with Allied Corp. and Westinghouse to produce amorphous material suitable for use in distribution and power transformers on a pilot plant scale. A pilot plant was constructed and later sold to Allied that produced wide (6.8-in, 173-mm) and thin (1.5-mil) amorphous metal in sufficient quantities to prove the capability of a continuous process with controllable magnetic and physical characteristics (RP1290).

The main objective was to achieve low-loss material characteristics. This goal was achieved and the initial target for loss reduction was exceeded significantly. Further work will continue on a separate contract to produce thick (5–10-mil) and 8-in-wide (203-mm) material for use in stacked core power transformer projects.

A Westinghouse companion project for evaluating the characteristics of the material and the application to transformers confirmed our hopes for the material's application. However, Westinghouse showed that this material cannot be applied to the transformer in the same manner as conventional steel. Consequently, two projects have been initiated for the development of new construction methods for distribution and power transformers (RP1592—funded as a part of the Distribution Program—and RP2236). *Project Manager: Edward T. Norton*

UNDERGROUND TRANSMISSION

Underground obstacle detection and mapping systems

Crowded conditions below city streets make for difficult excavation and unforeseen costs when installing underground transmission cable—in addition to the danger of rupturing pipes and disrupting other utilities. A project was initiated to devise a means of detecting both the depth and location of underground utilities prior to excavation (RP7856). The intent was to design and build a ground-penetrating radar system that would help map pipes and obstacles, thus alerting crews and equipment operators to the location of potential hazards, such as gas mains.

The equipment that was developed can detect both metal and plastic pipes. With the help of computer-enhanced projections (a printout of dots, the density of which implies the image of an obstacle) a plan view and vertical cross sections are obtained, and an image similar to a CAT scan is produced for various depths, according to need. This detection and mapping process can be accomplished at speeds up to 10 mi/h (16 km/h). An antenna located in a cart is connected by cables to a computer, and interface equipment is housed in a cargo van. Both resolution and depth of scan depend on the electrical conductivity of the soil; the lower the conductivity (the drier the soil), the deeper the penetration, with a maximum depth of 10 ft (3 m). Resolution remains at approximately 4 in (102 mm) throughout, and it appears that this will be possible in most soils.

The unit has been shipped to EPRI's Waltz Mill Underground Cable Test Facility and is available for utility field tests and evaluation. *Project Manager: Thomas J. Rodenbaugh*

Determining transfer capability objectives

The ability to transfer electric power from one utility operating area to another is called transfer capability; the level of capability appropriate for an individual utility is called a transfer capability objective. To select an adequate objective, planners must evaluate many conflicting factors, including capital costs; environmental impacts; and the need to share resources, obtain lower-cost energy, and reduce dependency on a single type of fuel. Until now, only broad guidelines, rather than detailed procedures, have been available for this complex evaluation.

This project was initiated to develop and test a means by which a utility can analyze and compare the costs and benefits of power interchange and thereby choose the appropriate level of transfer capability (RP1960).

Researchers used strategic planning techniques to develop a procedure that considers all the aforementioned costs and benefits involved in setting a transfer capability objective, including the effects of technical and company constraints. Existing computer programs were surveyed, and where necessary, special-purpose computer programs were developed. The entire procedure was tested on a three-area interconnected utility test system. This system was based on an actual power pool and thus had realistic system characteristics and constraints.

A standardized, step-by-step procedure for determining transfer capability objectives was developed that uses both existing and new computer programs. In steps 1 and 2, the planner uses traditional analytic methods to identify the transfer capability, cost, and attributes (such as reliability and production cost) of a variety of planning options. In step 3, new methods and computer programs automatically generate many plans from the data available. In step 4, the planner compares the trade-offs of interconnection with other strategies and selects the most desirable plans from the options generated. In step 5, the planner identifies the single best plan, which is associated with a specific transfer capability. In the final step, the planner can perform sensitivity studies to assess the susceptibility of the transfer objective to uncertainties.

The contractor is to be commended on the results achieved in this study of a complex, elusive, and easily misunderstood topic. In response to utility needs, the research produced a new, well-documented procedure that organizes and extends planning techniques currently used to set transfer capability objectives. Potential users should understand, however, that (depending on current planning practices) the approach initially may involve much work. Further, a utility must have a statistical analysis package and know how to use it. Volume 1 of the final report (EL-3425) documents the procedure; Volume 2 is a user's manual. *Project Manager: James V. Mitsche*

OVERHEAD TRANSMISSION

Structural development

Data for EPRI's structural development project are now becoming available in significant quantities from the research and cosponsored testing being conducted at the Transmission Line Mechanical Research Facility (TLMRF). TLMRF has been operational for approximately five months under an EPRI operations contract with Sverdrup Technology, Inc., of Tullahoma, Tennessee. After two years in construction and six months of site shakedown and testing, TLMRF is supplying the full-scale test data required by the EPRI structural development project and the industry (RP1717).

One of the main objectives of the testing conducted at TLMRF is to improve and experimentally validate structural computer programs used to design and analyze transmission lines. To accomplish this objective, multiyear research tasks have been implemented as part of the research, which focuses on the behavior and performance of individual components and complete transmission line systems.

Because of the variety of structures and hardware used on transmission lines, project results and software must be applicable to a wide variety of conditions. This requires test data on many different types of structures and loading conditions. In the past, transmission structural computer software has been validated with a very limited number of full-scale test cases, at best. This condition did not exist from choice but because the majority of structural testing was not done to provide engineering data for research and validation purposes; rather, testing was done as proof load or acceptance testing of the subject structure. Significant amounts of correlated load, stress, and deflection data are not a normal part of proof or acceptance testing. In many cases, a single commercial proof-testing organization does not have the opportunity to analyze and test the wide variety of structures that exist in the utility industry today.

EPRI's intent is to conduct a wide variety of research and cosponsored tests at TLMRF for utilities and fabricators and to perform this testing with an experienced testing staff supported by a full-time structural research group. While satisfying the requirements of the cosponsoring utility/fabricator, this team will obtain the maximum amount of data possible in order to understand the behavior of the subject structure and to validate and improve the EPRI design and analysis software.

A further requirement is that this more-extensive testing be completed in the same timeframe as a traditional proof test. In practice, TLMRF has shown that it can meet these objectives. Because of the efficient design of the site, not only can the structure be rapidly set up for testing but the array of test instrumentation required to gather the desired data can also be quickly and efficiently put in place.

The data obtained as a result of testing at the TLMRF site are accurate and verifiable. The data not only give an accurate picture of the capabilities of a particular structure but also provide an accurate comparison between various types of structures. Against this array of data, a number of different design and analysis methods are run to determine the effect and consequences of various simplifying assumptions. In this manner the best set of computer codes will emerge for the utility industry.

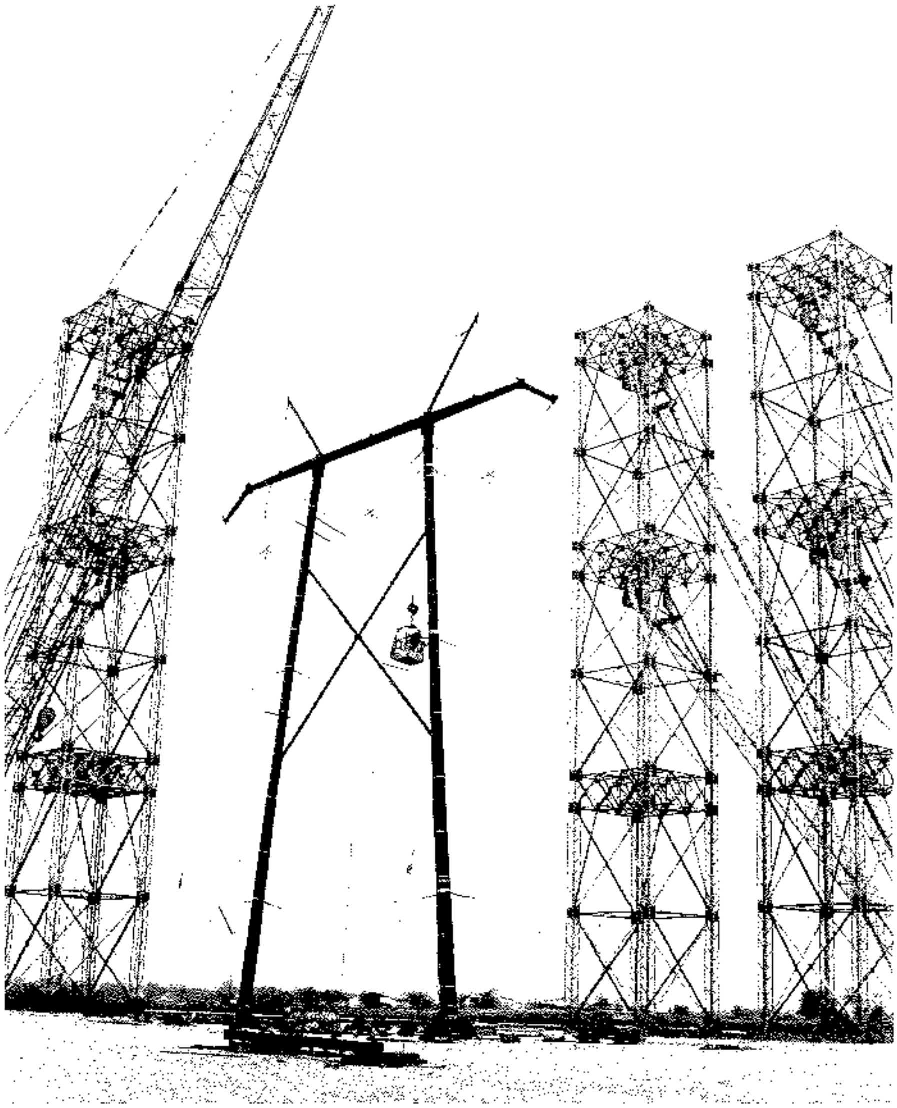
A major advantage of this research testing for the cosponsoring organizations is a research report, which contains an analysis of the test data and a comparison of the data with results obtained from the research software being developed or verified at TLMRF. In addition, the research results become part of a data base, which is used in conjunction with other research data to improve the design and understanding of a specific class of hardware. In the long run, this continuous scrutiny of the test data will benefit the entire transmission line industry.

Five internal research tests and five cosponsored tests have been completed at TLMRF. These tests covered a cross section of the transmission structures used—from single pole to H-frame to lattice tower. Two recent examples of tests performed at TLMRF illustrate the approach used at the site. First, a 345-kV single-circuit lattice structure was tested for the Public Service Co. of New Mexico (PSNM) and Anchor Metals of Hurst, Texas. Readings on 78 strain gages, plus deflections and loads, were taken for each load case and load level. This provided a wealth of data for comparison with analytic results. The test data were then compared with the results of four analyses. These analyses included a frame truss solution, a tension-only solution, a truss-only solution, and a nonlinear finite element solution. By comparison of full-scale test data from this and subsequent tests, the various computer techniques can be verified and improved.

In addition to the normal load cases, a study of the effects of foundation movement in uplift and compression was included as part of the PSNM test. Stresses were recorded for a series of leg vertical deflections with and without the application of loads to the structure. An analysis of these cases was also made and the results compared. This is the first step in producing a combined foundation-structure analysis computer code.

A second example of a recent test is a 500-kV single-circuit steel H-frame tested for Florida Power & Light Co. and Valmont Industries of Valley, Nebraska (Figure 5). For this test 7 three-axis deflection readings and 24 strain gage readings, plus loads and base deflection data, were taken for each load case and load level. These data were then compared with a number of analyses, as in the first example. All these data are being kept on file as part of the structural development project data base for comparison with later full-scale tests of similar class structures. In this manner, the software will be validated for the full range of transmission structures.

Figure 5 Workmen in the basket suspended from the crane adjust wind load connection to the 500-kV tubular steel H-frame structure. Note the complexity of the rigging: Three cables are attached to each of five pull points, and two cables are attached to each of six pull points. Thus to load the structure, 27 winches are controlled simultaneously.



The software validation and full-scale testing will not stop with the testing of single isolated structures on the test pads. Construction is beginning on the first of three 2-mi (3-km) test lines, where structures similar to those tested on the test pads will be subjected to both static and dynamic loadings. This first line will be operational in 1984. The test line data will be compared with the test pad results. Various transmission line and component computer simulations will be made. The net result of assembling and analyzing these data will be more-realistic test pad testing and better-validated transmission line software.

All this accumulated knowledge will be available to the utility industry through the package of structural design and analysis software being developed as part of EPRI's structural development project. The first important steps are now being taken to support significant improvements in overhead transmission lines of the utility industry. *Project Manager: Paul Lyons*

Polysil field test stations

Thanks to the utility sponsors of the Polysil field test stations, the industry is learning how Polysil insulators will perform in various locations under energized field conditions. Even though the laboratory tests showed that the material performs well as an electrical insulator, the only test that provides complete confidence in a new material is actual in-service performance. This was the primary reason for constructing test racks containing a standard porcelain 69-kV insulator and 17 Polysil insulators.

To date, we have over two years' field exposure on most of the 25 racks, and the performance of Polysil insulators is good. Because we are very familiar with the performance of porcelain post insulators, a good question is how the performance of Polysil insulators compared with that of the porcelain unit. From reports by the host utilities to Pennsylvania Power & Light Co., all indications are that the Polysil units are performing as well as, and in some cases better than, the porcelain insulators. The test racks are located in every type of climate and exposure; results to date show that Polysil is a suitable material for outdoor insulation in all areas of the United States. PP&L will continue to receive reports from the host utilities until the end of the test period in mid 1984, combine all the data, analyze the results of the tests, and prepare a final report.

Aside from a test of the durability of Polysil in the field, an equally important objective of these tests is to determine the effects of varying material and design parameters to optimize the performance of the insulator. Each test rack is identical and has 18 types of insulators. Seventeen of the insulators are Polysil and one is a standard porcelain unit. There are two Polysil formulations, two shed designs, three types of coatings, uncoated units, and three types of voltage grading.

By comparing the performance of the individual units, it can be determined which combination of parameters works best. Although a complete analysis will be delayed until the end of the three-year test period, indications are that the simple design performs the best. This is the insulator without a coating and electrically graded by properly shaping the end caps that are cast into the insulator. It might have been suspected that the coated insulators with their slick, shiny finish would shed contaminant better, but inspection of the insulators does not show this. Also, grading the insulators with internally cast resistors or capacitors theoretically should have improved their performance, but field observations do not indicate any improvement. This is really good news, for it means that the simple, least-costly design is the best.

For utilities, the most important fact is that the hope of a lower-cost material for overhead line insulators is reaching fruition. Now that Polysil insulators are becoming commercially available from several licensees and the field tests indicate the durability of the material in actual service, utilities will want to take advantage of the cost savings afforded by this new material. *Project Manager: John Dunlap*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Vice President

MEASURING RESIDENTIAL CONSERVATION PROGRAM IMPACT

Under EPRI sponsorship an innovative method of measuring the incremental impact of utility demand management programs for residential customers has been developed (RP1587). The approach is designed to analyze utility demand management actions and, more important, to distinguish between impacts directly attributable to a utility program and naturally occurring, or price-induced, impacts. The method is suitable for evaluating programs already in place or for estimating the impacts of potential future programs. Data from one utility have been used to demonstrate the method on a conservation program—just one of the various types of load management and marketing programs to which it is applicable.

Electric utilities have spent millions of dollars over the past decade on strategic conservation programs designed to encourage customers to use less electricity and to use it more efficiently. The programs involve a variety of approaches, ranging from information dissemination and weatherization audits to financial incentives (loans and rebates) for weatherizing or purchasing more efficient appliances.

Many utilities are uncertain about how to accurately assess the net impacts of their investment in conservation programs. Considerable progress has been made in developing mechanisms for incorporating the whole range of demand-side management activities, including conservation, into the utility planning process. However, such mechanisms require accurate estimates of the impacts of demand-side programs in order to evaluate their cost-effectiveness against that of supply-side options. Relatively limited data collection and analysis efforts have been undertaken in this important area.

Analytic problems and approaches

Measuring the impact of utility conservation programs is a complex task, largely because of the vicissitudes of consumer behavior. The key problem for utilities in evaluating such programs is to separate out direct, program-induced conservation—called strategic conservation—from naturally occurring, or price-induced, conservation.

Conservation typically involves either efficiency improvements (e.g., enhancing the thermal quality of a dwelling or purchasing more efficient appliances) or actions to reduce the use of an energy service (e.g., turning down the heat or hanging out the wash). Efficiency improvements create a clear potential for reduced energy consumption—a potential that can be simulated by engineering calculations. However, improved efficiency also lowers the effective cost of the relevant energy service to customers. As a result, they may well opt to consume some of the potential savings in the form of greater use of that service; or they may take advantage of savings in one area to increase their use of another energy service.

Actual energy savings, then, cannot be assumed to equal the potential savings enabled by efficiency improvements. Similarly, the true market penetration impact of a utility conservation program cannot simply be considered the sum of actions undertaken by customers participating in the program. Some customers would have taken some or all of the actions even without the program. In many cases utility programs may serve merely to accelerate consumer behavior that would have occurred anyway. The incremental actions directly caused by a program must be inferred indirectly by analyzing the behavior of both program participants and nonparticipants.

A number of methods have been used or proposed for analyzing the impact of utility conservation programs. They range considerably in cost and complexity, as well as in their ability to address the methodology issues described above. Most approaches focus on the need to estimate how program participants would have behaved in the absence of the program. One common approach is to subtract from total participant savings the savings of a control group of nonparticipants. Unfortunately, this procedure results in a statistical problem known as self-selection bias; that is, households electing to participate in a utility program are likely to differ from nonparticipants in a number of important ways. For example, they are likely to have a greater potential for saving energy, a greater awareness of conservation, and a greater probability of taking conservation actions in the absence of utility programs. Thus the use of nonparticipant control group savings in determining net savings will likely lead to an overestimate of a program's effect.

Self-selection bias can be eliminated by making a more complex analysis to account explicitly for, and thus control for, as many factors as possible that affect energy consumption and savings. A typical approach is to model electricity consumption in terms of such variables as household demographics, dwelling characteristics, appliance holdings, program participation, and conservation actions taken.

Called the conditional demand approach, this method can help resolve the self-selection bias problem. It does not address another problem, however, one formally known as simultaneous equation bias. This problem arises because of the relationship between choosing to consume electricity and choosing to participate in a utility program. If the feedback between choices is not accounted for, conditional demand estimates will themselves be biased.

The method developed in RP1587 by Arthur D. Little, Inc., combines features of end-use analysis and econometric analysis. It is a multiequation approach that represents consumer behavior at each of the decision points relevant to a utility conservation program—the decision to participate in the program, the decision to take specific conservation actions, and the decision to use appliances and thus consume electricity. The parameters of these behavioral equations are estimated on the basis of utility survey and billing data. The equations can then be used to determine the net impact of a utility conservation program by simulating consumer behavior both with and without the program.

Methodology application

To demonstrate this method, the EPRI project team estimated the parameters of a particular set of behavioral equations by using an extremely valuable body of data collected by Portland General Electric Co. (PGE) as part of its evaluation of a weatherization audit and zero-interest loan program called ZIP. The sequence of decisions faced by all eligible PGE customers (i.e., customers with electric space heating) is shown in Figure 1. Completion of an audit was a requirement for obtaining a ZIP loan.

PGE collected survey data from a sample of those eligible households that had participated in the audit program during a 16-month period in 1978–1979. Data were also collected from a sample of nonparticipants. Billing and weather data for one year before and two years after the program participation period were matched with the survey information. (It should be noted that utilities have collected and analyzed relatively little information of this type, a fact indicated by a limited survey of utilities active in conservation that was undertaken as part of RP1587. This lack of data was also pointed out at two recent conferences—an EPRI workshop on measuring conservation effects, reported in EA-2496, and the National Conference on Utility Conservation Programs, held in New Orleans in September 1983 and reported in EA-3530.)

The EPRI project's analytic approach consisted of modeling a household's choice at each of the decision points in Figure 1. The decisions to request an audit, obtain a ZIP loan, and take certain weatherization actions are discrete (yes/no) choices and were thus analyzed by a particular type of discrete-choice econometric model called a logit model. Such models relate the probability of taking an action to a set of explanatory variables, including customer demographics, awareness of utility programs, and, for

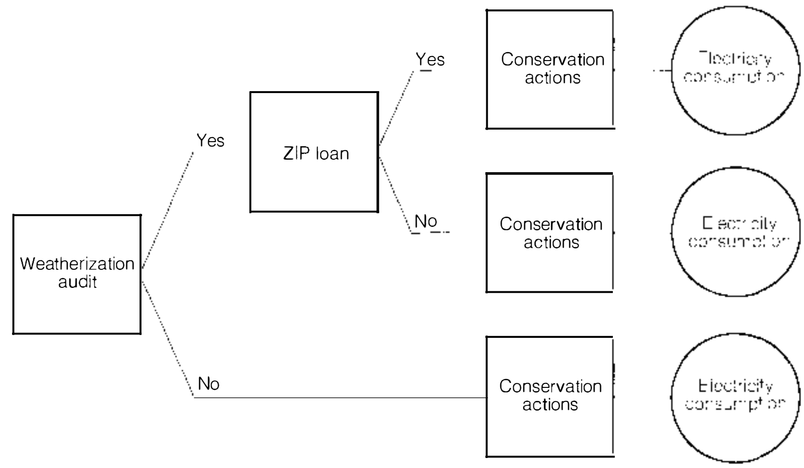


Figure 1 This decision tree shows the choices faced by customers eligible to participate in Portland General Electric Co.'s weatherization audit and zero-interest loan program (ZIP). EPRI has sponsored the development of a method for measuring the impacts of such utility demand-side management programs. The method combines end-use and econometric analytic techniques to model consumer behavior both with and without a program.

Table 1
WEATHERIZATION AUDIT REQUEST PROBABILITY: DESCRIPTION OF HOUSEHOLD TYPES

Independent Variable	Household Least Likely to Request Audit (probability = 0.0003)	Average Household (probability = 0.24)	Household Most Likely to Request Audit (probability = 0.80)
Occupancy status (1 = owner, 2 = renter)	2.0	1.05	1.0
Age of household head (3 = 25–34, 6 = 65 or over)	6.0	4.8	3.0
Education of household head (1 = college, 4 = no high school)	4.0	2.5	1.0
Length of occupancy (yr)	59.0	10.7	1.0
Awareness of utility advertising (1 = aware)	0	0.62	1.0
Number of residents aged 25–34	2.0	0.38	0

Note: For each household type, the average value of each variable is given.

weatherization actions, the estimated cost and savings of each action. Finally, a conditional demand equation was estimated in which electricity consumption depends on household demographics, dwelling characteristics, weather conditions, and whether or not the household requested an audit and/or took specific weatherization actions.

The modeling results for audit choice are reported in Table 1. The probability of requesting an audit is shown for three hypothetical household types that represent parts of the sample cross section. The table describes each type of household by presenting values for the explanatory variables used in the equation. The average household, as characterized by the middle column of figures, requests an audit with a probability of 0.24. The other columns of figures present extreme cases of hypothetical households with maximum (or minimum) values for those factors that most strongly affect the probability of choosing an audit. For example, the most likely audit requesters are relatively young, highly educated homeowners who have lived in their house only a short time.

Similar tables can be constructed for the ZIP loan and weatherization action choices. It should be clear that each component of the analysis by itself can provide valuable insights helpful for utility planners—for example, in targeting programs toward or away from particular market segments. However, the value of the approach can best be seen by integrating the separate components of the analysis, the choices at each decision point. The resulting set of models can be used to simulate household behavior under alternative scenarios, such as with or without a utility program. Two obvious applications are a retrospective evaluation of a past or existing program, where the behavior of program participants is of most interest, and a prospective analysis of the likely impact of a future program, where the focus is on all eligible customers in order to determine who will participate and how much energy they will save.

Table 2
IMPACTS OF AUDIT-LOAN CONSERVATION PROGRAM
(MWh/yr)

	Household Least Likely to Conserve	Average Household	Household Most Likely to Conserve
Electricity consumption			
Average preprogram consumption	22.2	23.4	24.4
Simulated postprogram consumption	23.4	22.6	20.3
Simulated consumption without program	23.4	23.0	22.1
Electricity savings			
Total savings with program	−1.2	0.8	4.1
Savings without program	−1.2	0.4	2.3
Incremental savings attributable to program	0	0.4	1.8

Table 2 presents results from a sample prospective analysis in which the EPRI project team used data from PGE to simulate the effects of the utility's audit-loan program on all eligible customers. The first three rows show electricity consumption under different scenarios for the three hypothetical household types introduced above. The last three rows show corresponding electricity savings.

The difference between average preprogram household consumption and simulated postprogram consumption represents the total electricity savings that would result after program implementation. This measure, however, includes savings that some households would achieve even if no program existed. To account for this naturally occurring conservation, the researchers simulated household consumption with no program in place (i.e., the households face no audit or ZIP loan choices, and weatherization actions do not depend on audit and ZIP participation). The incremental program savings are the difference between simulated consumption with and without the program. For the two household types with a reasonable probability of participating, the incremental savings constitute between 40% and 50% of total savings.

This illustration does not represent a comprehensive evaluation of the PGE program. However, the simulations of electricity consumption with and without the program are based on analyses of the actual behavior of the utility's customers at a given time, and they do indicate a clear potential difference between total and net conservation program impacts.

The applicability of the analytic method developed under RP1587 is not limited to conservation programs, but extends to any utility marketing program designed to influence consumer behavior. For example, a similar set of equations could be developed to analyze the impact of a rebate program to encourage installation of heat pump water heaters. *Project Manager: Steven Braithwait*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Vice President

SUPERCONDUCTING MAGNETIC ENERGY STORAGE

Superconducting magnetic energy storage (SMES) is the only known method for directly storing energy in the form of electricity. All other storage concepts convert the electricity to another form of energy (e.g., thermal, mechanical, chemical) and then reconvert it to electricity prior to use. SMES, however, stores the energy as an electric current passing through an inductor. The inductor, made from special alloy metals in a circular geometry, exhibits near-zero resistivity when kept at temperatures approaching absolute zero, which allows the current to circulate with virtually no energy losses. A recent assessment of SMES shows it to be technically feasible and to have excellent performance characteristics, but its cost is about twice that of commercially available energy storage power plants. Thus, SMES commercialization will require long-term R&D to bring costs down, as well as to resolve certain inhibiting environmental issues.

Certain aspects of SMES make it appealing to electric utilities for load leveling. Its storage efficiency (ac electric energy out divided by ac electric energy in) can be over 90%. It should have a long plant life (~50 years) and a very high plant reliability because of its few moving parts and relatively low constant temperatures. Electric response is virtually instantaneous (tens of milliseconds), enabling its use for system regulation and spinning reserve.

On the other hand, SMES has some features that detract from its appeal. Capital costs are high compared with other energy storage technologies: at least two times higher than batteries, pumped hydro, or compressed-air energy storage. Because plant capital cost per kW can be reduced by only about 20% if plant size is doubled, early SMES plants will have to be very large to be economically competitive—about 5000 MWh, with a coil diameter over 1500 m. This will require a large capital investment and a long construction period. To minimize support structure cost, the coil must be built underground in a circular trench where anchors to the trench walls can support the magnetic forces. This places strict requirements on construction and quality control and increases maintenance costs if forced outages are caused by the underground coil. In addition, environmental issues related to the magnetic field and the large land requirements may delay licensing.

For several years utilities debated whether the advantages of SMES could compensate for its disadvantages, but until recently, they lacked sufficient information to make a credible determination of either SMES's capital cost or its value to a utility. By 1981, however, researchers at the University of Wisconsin and Los Alamos National Laboratory had developed conceptual designs and defined the necessary superconducting coil characteristics in sufficient detail to initiate detailed cost and technology assessments.

As a consequence, EPRI commissioned two assessment studies. One study, conducted by Energy Management Associates, Inc. (EMA), used modified generation expansion methodologies to determine the economic value of SMES to several hypothetical utility systems (EM-2861). The companion study, conducted by Bechtel Group, Inc., and GA Technologies, Inc., developed a preferred conceptual SMES design and examined its cost implications (EM-3457).

Economic value of SMES

The EMA study assessed the economic value of SMES to utilities in three separate scenarios.

- A conservative scenario, involving typical reference utilities, used "best estimates" of SMES characteristics (91% efficiency, 98% availability, and 5.5% refrigeration load).

- An optimistic scenario assumed 100% efficiency, 100% availability, zero refrigeration load, and an enormous utility (one-third the size of the United States) that could take full advantage of the SMES system's storage capacity.

- A most-reasonable scenario used a realistically sized utility, specifically configured to need energy storage, and assumed the same "best estimates" used in the conservative scenario.

For a 600-MW, 6000-MWh SMES plant in the conservative and optimistic scenarios, the study determined economic values of $800/kW and $1600/kW (1982 $), respectively. The most-reasonable scenario had an economic value of $1200/kW.

The EMA study assumed no other storage alternatives in developing these economic values of SMES. If, in fact, a utility could site other alternatives, such as compressed-air energy storage, pumped hydro, or underground pumped hydro, or if storage batteries should become available at a competitive cost, then the economic value of SMES would tend to approach the capital cost of other storage alternatives, or about $650/kW (Table 1). A reasonable value for SMES under those conditions is $800–$900/kW when proper credit is given for the high efficiency and fast response of SMES.

SMES technical feasibility and cost estimate

The design and cost assessment study conducted by Bechtel and GA Technologies was structured to accomplish the following.

- Establish a preferred conceptual design based on near-term extrapolations of state-of-the-art technology

- Consider the feasibility of fabricating that design

Table 1
CAPITAL COST COMPARISON: ENERGY STORAGE TECHNOLOGIES
(1982 $)

Technology	Capital Cost[1]: Power Related ($/kW)	Capital Cost[1]: Energy Related ($/kWh)	Capital Cost[1]: Total: 5-h Storage ($/kW)	Efficiency: Round Trip[2] (%)	Efficiency: Overall[3] (%)
SMES					
State of the art	194	231	1349	91	31
+15 years' R&D	158	143	873	91	31
Pumped hydro	600	10	650	70	24
Underground pumped hydro	575	30	725	70	24
Compressed air	490	10	540	—[4]	30
Thermal (oil)	600	45	825	70	24
Batteries					
Lead-acid	100	140	800	75	26
Advanced	100	100	600	70	24
Hydrogen-air	750	12	810	50	17
Hydrogen-halogen	425	35	600	67	23
Flywheel	120	340	1820	85	29

[1]Capital cost is based on "overnight construction" and comprises two components; before they are added for a total, the energy-related component must be multiplied by the storage capacity (hours) to convert to $/kW.

[2]Round-trip efficiency refers to the energy storage technology only (ac in, ac out).

[3]Overall efficiency encompasses the entire energy system—from primary fuel through a 10,000 heat rate baseload power generator to energy storage technology, including any supplemental fuel used in the storage facility.

[4]Compressed-air energy storage requires 0.72 kWh (electricity) + 4000 Btu (oil or gas) to produce 1 kWh.

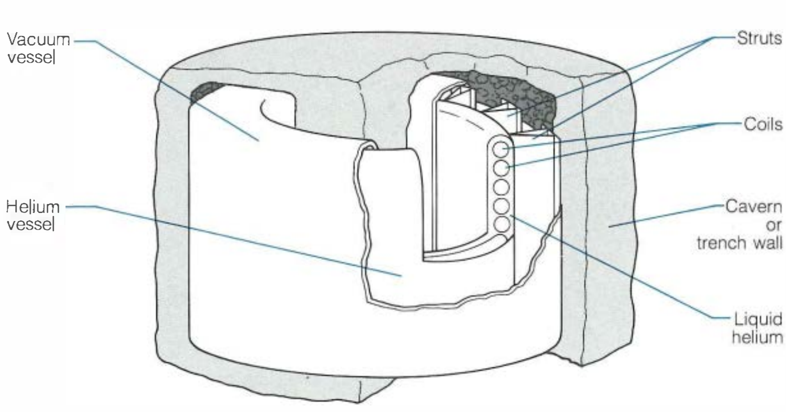


Figure 1 In the basic configuration for an underground SMES plant, the superconductor is wound as a solenoid coil and bathed in liquid helium that has been supercooled to about 1.8 K. (Illustration not drawn to scale.)

- Develop a cost estimate for the preferred conceptual design based on state-of-the-art technology
- Identify R&D issues
- Define the potential for future cost reductions

The study efforts are now complete and the report will be published this year. The study's preferred design uses a single-layer, 112-turn, solenoidal superconducting coil (Figure 1). The coil employs a high-current (765 kA) conductor made of copper-niobium-titanium alloy wire, fabricated into flat cable and encased in high-purity structural aluminum. The aluminum not only acts as a current stabilizer but it also absorbs energy during emergency shutdown and supports the superconducting cable, which must resist daily magnetically induced tensile and compressive loads. The superconductor operates at a nearly constant temperature of 1.8 K.

The 1.5-km-diam coil is housed in a 2.4-m-deep bedrock trench, whose outer wall provides support against outward radial loads when the coil is charged. The radial forces are transferred from the coil to the trench wall through a system of cold-to-warm epoxy struts that bear against vertical supports attached to the trench wall. The axial compressive forces are resisted by aluminum bricks that separate the adjacent 112 turns of the coil.

The coil is immersed in a superfluid helium bath cooled to 1.8 K; a helium containment system surrounds the coil and its axial support structure.

A closed-cycle refrigeration system removes heat from the helium through a series of cryogenic "necks" that penetrate the helium vessel. To minimize heat transfer, the cold components operate in a vacuum enclosure that surrounds the helium vessel, with two thermal shields between the enclosure and the cold helium vessel wall. The total refrigeration load for the preferred design is estimated to be about 5 MW.

The coil is charged and discharged through an ac-dc power conditioner. Ac is converted to dc, which charges the coil, and the stored dc is reconverted to ac before transmission back to the utility grid. The power conditioning equipment is about 520 m from the coil perimeter, where the magnetic field strength at peak coil charge is 100 gauss (0.01 T). Superconducting leads extending from the coil to the vicinity of the power conditioning system are connected to the cold-to-warm transition leads of an ambient temperature copper busbar. The total round-trip (ac-dc-ac) efficiency of the SMES plant (including the power conditioning system) is estimated to be about 90%.

The projected capital cost for this preferred design (sized at 1000 MW, 5000 MWh) would be $1349/kW; this comprises $194/kW (power-related) and $231/kWh (energy-related) components. (Note: The power plant capital cost is calculated as $194/kW + $231/kWh × 5 h = $1349/kW.) This capital cost is higher than the most-reasonable economic value of $1200/kW developed in the EMA study and considerably higher than the costs of commercially available energy storage alternatives, such as compressed-air energy storage or pumped hydro.

An analysis of the capital costs for the preferred design indicates that over half the costs are related to the conductor coil material, its axial support structure, and its fabrication. Projections are that sustained R&D over a 15-year period focused on superconducting materials, cable design, and related support systems could reduce the energy-related costs by about $88/kWh. This would lower the plant capital cost to about $873/kW, which would be cost-competitive with other storage technologies when the high efficiency of SMES is properly considered.

Future R&D efforts

As a result of this analysis, EPRI is initiating a low-level R&D effort focused on reducing the cost of the coil-related items. This effort will include developing a conductor having a higher current density and/or a lower cost; optimizing the cost of the conductor configuration; developing lower-cost alternatives to the aluminum coil axial support structure for energy absorption during coil emergency shutdown; reducing the helium requirements; and optimizing the design/cost plant system parameters.

The major area of interest is the conductor. Improving the existing niobium-titanium conductor's current density, a likely R&D outcome, will result in a sizable reduction in plant cost. Use of other superconductor materials with even higher current densities, such as niobium-tin or some completely new material, is a longer-term possibility.

Improving the basic understanding of possible SMES disturbances (another R&D area of interest) will allow for less-stringent criteria in the cable design, thereby reducing the quantity of high-purity aluminum in the conductor (a large cost factor). This type of R&D requires experimental as well as analytic work.

The use of aluminum for stabilization also means that techniques must be developed to economically manufacture large volumes of high-purity aluminum (by fractional crystallization) and to solder the fabricated aluminum components with a high degree of success. Prototype testing of such a high-current conductor also appears to pose a problem that will need resolution. *Project Manager: Robert B. Schainker*

FLEET EV BATTERY OPTIONS

Electric transportation could displace a significant portion of the approximately six million barrels of oil used daily in the United States. Options for electric transportation include electric vehicles (EVs), hybrid vehicles, electric mass transit, electrified railroads, and electrified highways. EPRI's activities have focused on the EV because it shows the largest potential for petroleum substitution (light trucks and cars currently consume about 92% of all petroleum used in transportation). Within this focus, EPRI is concentrating on commercial fleet applications, which offer the best promise of an entry market for EVs. For both fleet and general-use applications, however, further development of EV batteries is necessary. EPRI is involved in a variety of projects to develop and evaluate battery options for fleet EVs. Related activities were discussed in the EPRI Journal *issues of March 1981, p. 52; September 1982, p. 58; and March 1983, p. 46.*

A number of EVs have been manufactured and demonstrated in the United States and abroad in the past few years. Until recently, however, only limited data existed on their performance characteristics and on their impact on the electric utilities that will be called upon to supply their power. To help develop this data base, EPRI initiated an electric transportation R&D program in 1981. This program focuses on testing and evaluating currently available EVs, developing key EV components, and preparing for large-scale field tests.

At present EVs cannot compete in the marketplace with conventional internal combustion vehicles; such vehicles have high performance levels, virtually unlimited range, relatively low first cost (as a result of volume production), and an extensive infrastructure to support their distribution and operation. However, widespread use of EVs not only could significantly reduce the country's dependence on oil but also could enable a more-efficient use of its electric generating capacity through off-peak EV battery recharging that uses economic baseload power.

An attractive first market for EVs is commercial fleets. In this market an extensive external infrastructure is not required, and range and high performance do not carry the premium they do in the general-use market. Also, although the first cost of EVs is higher than that of their petroleum-based counterparts, their life-cycle cost is likely to be lower; this makes them more attractive to fleet owners than to owners of private vehicles.

Electric utilities are ideally situated to conduct an early demonstration of EVs within their own vehicle fleets and at the same time obtain valuable experience in developing an energy supply and vehicle service infrastructure. To promote this effort, a number of utilities recently formed the Electric Vehicle Development Corp. (EVDC). As one of its first activities, EVDC established a set of preliminary performance characteristics that would make EVs acceptable to other fleet operators.

Payload	455 kg (1000 lb)
Minimum range	60 mi (97 km)
Acceleration	Diesel equivalent

In support of the EVDC initiative, EPRI is focusing on the development and evaluation of batteries capable of powering fleet EVs. By adopting design criteria that would meet the vehicle performance characteristics proposed by EVDC (e.g., proportion of vehicle as battery weight or dc energy consumption per mile), EPRI drew up a corresponding set of battery performance guidelines (Figure 2), which include the following.

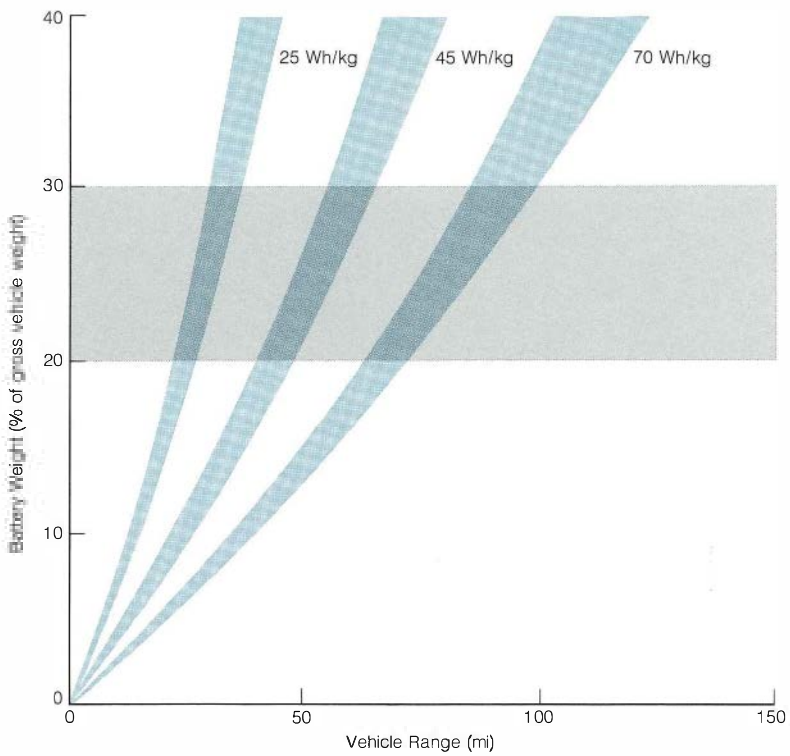
Capacity	24 kWh
Specific energy	45 Wh/kg
Energy density	80 Wh/L
Specific power	90 W/kg (80% discharged)

To take into account cost as well as performance, EPRI established an equipment and manufacturing cost goal of $100/kWh with a life of 1000 charge-discharge cycles as a reasonable estimate.

Using these cost and performance guidelines, EPRI has evaluated seven different types of batteries for fleet EV use: lead-acid, nickel iron, nickel zinc, zinc chloride, zinc-bromine, sodium-sulfur, and lithium–metal sulfide. Although at present none of these batteries meet all the cost and performance guidelines, development is continuing with EPRI, DOE, and private sector support.

Until recently, prototype EVs were powered exclusively by commercially available lead-acid batteries. None of these batteries, however, meet the 45-Wh/kg specific energy criterion, nor do they have a life approaching 1000 charge-discharge cycles. Moreover, in demonstrations to date they generally have required excessive maintenance and/or repair. A number of projects,

Figure 2 EPRI battery guidelines target a specific energy of 45 Wh/kg for fleet EV applications. As specific energy rises with increasingly advanced battery technologies, the EV range will also rise for a given battery weight. The gray area indicates the battery weight range typical of fleet EVs. Each color area represents a payload range of 500–700 lb (227–317 kg).



therefore, are exploring ways to improve the lead-acid battery for EV use.

The Globe Division of Johnson Controls, Inc., has been developing improved state-of-the-art (ISOA) lead-acid batteries in a DOE-funded program for several years. Although compared with commercially available lead-acid batteries these prototypes are more efficient, weigh less, have higher specific power, and are longer lived, they still do not meet the EVDC guidelines for specific energy, specific power, or cycle life. Globe's continuing program is addressing the need for these performance improvements.

EPRI is evaluating the impact of peak power, charge routine, and temperature control on the Globe ISOA battery's cycle life under urban driving conditions at Argonne National Laboratory's (ANL) National Battery Test Facility (RP2216-2). In addition, EPRI is supporting a sealed lead-acid battery development project at the Jet Propulsion Laboratory (RP2216-1). This battery, which uses an immobilized electrolyte and horizontal plates to achieve high specific energy and high power density, is projected to have performance characteristics suitable for fleet EV applications. To determine life and reliability parameters, EPRI is also evaluating several lead-acid batteries (including European tubular designs and the Globe ISOA systems) at TVA's Electric Vehicle Test Facility (RP1136-18).

Nickel iron batteries for EV applications are available as engineering prototypes from Eagle Picher Industries. These batteries use sintered electrodes, which have demonstrated long life (approaching 1000 cycles) and have a specific energy that meets the fleet EV guideline. Sintered electrodes, however, are expensive, and their specific power is somewhat lower than the 90-W/kg requirement. Further, at this time the charge-discharge efficiency of nickel iron batteries is low; without improvement, the batteries would have an operating cost greater than that of the more-efficient lead-acid batteries. This low efficiency also makes frequent watering necessary, raising the possibility of high maintenance costs. Although the first cost of nickel iron batteries is projected at $120/kWh, outside analysis has yet to confirm this estimate. A nickel iron battery supplied by Eagle Picher Industries currently is undergoing in-vehicle evaluation at TVA (RP1136-18).

Nickel zinc batteries, developed with DOE and private sector funding in the late 1970s, appear to have the performance characteristics necessary for fleet EVs. Engineering prototypes developed by General Motors Corp. have demonstrated a specific energy of 52 Wh/kg and a specific power well in excess of 100 W/kg. The projected first cost of nickel zinc batteries, however, is comparatively high, and the life observed in both bench and road tests falls far short of the 1000-cycle goal. DOE is supporting research to improve the battery's cycle life, and EPRI plans an in-vehicle evaluation of a GM nickel zinc battery in 1984 (RP1136-18).

Zinc chloride batteries for both EV and load-leveling applications have been under development for over 10 years by the EDA Division of Gulf+Western Industries, Inc., with DOE and EPRI funding. In a demonstration of this battery in a specially designed passenger vehicle, EDA obtained a specific energy of 64 Wh/kg, a specific power of 59 W/kg, and an energy density of 60 Wh/L (an energy density as high as 100 Wh/L may be possible through improved chlorine hydrate storage). Although the charge-discharge efficiency of zinc chloride batteries is somewhat low, their electrode materials are long-lived (1700 cycles demonstrated on a 1.7-kWh unit). Cost projections by EDA for load-leveling batteries of this type indicate that their first cost for an EV application may also be acceptable.

The large number of auxiliary components in zinc chloride batteries, their maintenance needs, and their as yet undemonstrated reliability may prove a problem. For example, a refrigerator is required during charge to cause formation of chlorine hydrate, a solid compound that stores elemental chlorine. At present EDA uses an off-board charger that includes a refrigerator, but on-board chargers are more desirable for many fleet applications. Moreover, safety concerns about the elemental chlorine used in these batteries may inhibit their introduction for fleet EV use. The first independent assessment of EDA's zinc chloride EV battery (planned in 1984 at TVA) will involve in-vehicle evaluation of a battery with improved power characteristics (RP1136-20).

The zinc-bromine battery, like the zinc chloride battery, has a low volumetric energy density, low efficiency, and potentially high maintenance costs associated with auxiliary components. However, because the system does not require a refrigerator, it is somewhat less complex than the zinc chloride battery.

Exxon projects a specific energy of 60 Wh/kg for a zinc-bromine battery it is developing with DOE funding and has shown that the battery can achieve a specific power of over 100 W/kg. However, improved bromine electrodes may be required for this power to be available toward the end of discharge. Moreover, as now demonstrated, the life of these batteries falls well short of the 1000-cycle goal. Because Exxon has emphasized the use of low-cost materials, a battery price of less than $100/kWh may be possible. Exxon plans bench testing of its zinc-bromine battery within a year.

Sodium-sulfur batteries for EV applications have been under development by Ford Aerospace and Communications Corp. and several foreign developers for over a decade. This battery operates at approximately 350°C and uses a sodium-ion-conducting ceramic electrolyte and molten electrodes. The Ford program, supported by DOE, has now reached the stage of building and testing a full-size battery. Ford projects that this battery will have a specific energy of over 80 Wh/kg, a specific power of 200 W/kg, and an energy density approaching 100 Wh/L.

Test data on single cells, however, indicate that significant cell reliability improvements will be necessary before these batteries are ready for EV application. In addition, a number of cost issues remain unresolved, including the cost of thermal insulation necessitated by the high operating temperature. EPRI is funding work on sodium-sulfur batteries for load-leveling applications at General Electric Co. If the life-cycle cost of these batteries proves acceptable, their overall characteristics could make them most attractive for fleet EV applications.

Lithium–metal sulfide batteries are advanced high-temperature systems that use lithium-aluminum and iron sulfide electrodes with molten salt electrolyte. These batteries have been under development for several years by ANL, Gould, Inc., and Eagle Picher Industries with DOE funding. Their efforts have led to the development of prismatic monopolar cells with a specific energy of 85–90 Wh/kg, a specific power of 80 W/kg, and an energy density of 250 Wh/L. The performance values projected for lithium–metal sulfide batteries may be some 20% below the quoted values for single cells, but if the specific power can be improved the system should have performance characteristics suitable for fleet EVs. Although the cycle life of these cells (approximately 500 cycles) is still below that required, no fundamental failure mechanisms have been identified and the batteries should reach the 1000-cycle goal.

EPRI recently initiated the first phase of a development project leading to evaluation of this advanced battery in a fleet vehicle. This 20-month project with Gould (RP2415-1) and ANL (RP2415-2) will investigate the feasibility of fabricating a full-size battery by testing multicell modules at ANL's test facility, as well as develop and evaluate the thermal management and battery charging requirements for this high-temperature system.

In addition to its work on specific batteries, EPRI is currently undertaking cost analyses of a number of candidate fleet EV battery systems to determine their projected cost in both pilot plant and production quantities (RP1136-24 and RP1136-25). EPRI is also testing a number of battery auxiliary components at TVA to improve battery life and reliability; these components include thermal management systems, range meters, and advanced battery chargers. *Project Manager: David Douglas*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

TESTING NUCLEAR PLANT PIPING

To help the utility industry deal with the ever-increasing design and licensing requirements of nuclear piping systems, five years ago EPRI's structural integrity group in the Safety and Analysis Department initiated research on dynamic testing and analysis of such systems (RP964). The objectives of the research are to generate an experimental data base with which to assess and quantify current piping design conservatism, as well as to qualify analytic methodologies for more-realistic modeling and hence more-efficient piping design. Major tasks of the research include in-plant feedwater piping tests and analysis at Indian Point Unit 1 (RP964-2, -3, -4); seismic shake table tests of multiple-support piping at the University of California at Berkeley (RP964-8); and laboratory-based high-magnitude dynamic tests at Anco Engineering, Inc. (RP964-3, -9).

A typical nuclear power plant requires more than 20 mi (32 km) of safety-class piping, which accounts for 10–15% of the total project cost. These piping systems not only must support dead weight and normal operating loads but also must withstand low-probability severe seismic events and postulated thermal-hydraulic transients. Since the first commercial nuclear power plant, regulatory agencies and code-standard committees have taken numerous actions to develop conservative piping design and licensing criteria that will assure the safety of plant operation and plant shutdown. Such actions necessitated the design of piping systems that can accommodate extremely severe load and loading combinations. For example, plants must be able to handle both a postulated loss-of-coolant accident (LOCA) and a severe earthquake simultaneously. This capability for piping system integrity has to consider potential double-ended guillotine pipe breaks and associated jet impingement loads in the presence of a seismic SSE (safe shutdown earthquake), as well as OBE (operating basis earthquake) load levels. These regulatory actions have encouraged conservative or bounding approaches to piping design and analysis practice.

For example, current practices at various stages of seismic design have cumulatively imposed conservatisms on the piping systems in resisting potential seismic loads, including the use of site-independent input motions (NRC RG 1.60 Spectra) as plant design basis, frequency-broadened (RG 1.112) and amplitude-enveloped (NRC Standard Review Plan 3.9) seismic motions at all piping support locations, linear elastic method with lower-bound energy dissipation (RG 1.61 damping values) for analysis, and static load–based stress limits (ASME code) in seismic design.

The above requirements for nuclear piping design have generally led to the construction of stiff piping systems with a multitude of supports and snubbers. The resulting congested configuration and the requirement for frequent maintenance of this support hardware have degraded piping system reliability during normal operating thermal cycles. Plant shutdowns for in-service inspection, maintenance, and repair of the hardware have also contributed to increasing occupational radiation exposure and have imposed unique economic burdens on the utility industry.

Various government and industry organizations, therefore, have been taking steps to reevaluate the current piping design practices and to expand the body of knowledge on piping dynamic behavior. Most notably, the Pressure Vessel Research Committee (PVRC) of the Welding Research Council formed a steering committee on piping systems in January 1982. The objective of the committee is to assess piping design concerns with the goal of incorporating more-realistic standards into the ASME Boiler and Pressure Vessel Code and NRC Regulatory Guides.

The committee has identified four areas of improvements: system damping, floor spectra input, dynamic allowable limits, and industry practices. A technical committee, formed under the steering committee's direction, will draft technical positions for each area. So far, the committee has proposed interim positions on damping and input spectra.

Addressing similar concerns, EPRI has been carrying out piping research under its Risk Assessment Program since 1977. The main objectives of this research are the creation of an experimental data base to assess the degree of conservatism present in current piping design and to qualify analytic methodologies to more realistically model and more efficiently design piping systems. The areas of research include in situ piping tests and analyses, seismic evaluation of multiple-support piping, and dynamic capacity of pipings and supports.

In situ piping test and analysis

With the collaboration of Consolidated Edison Co. of New York, Inc., EPRI conducted a multiyear in situ piping test and analysis project at Indian Point-1 nuclear station (RP964-2, -3, -4). Researchers selected an 8-in-diam (20-cm) feedwater line inside the reactor containment vessel for a series of in situ dynamic tests. Objectives were to obtain state-of-the-art knowledge about the dynamic behavior of the piping system and realistic estimates of system response parameters, such as damping, pipe-support interaction, and system nonlinearity. The data were also used for analytic code benchmarking (RP964-5).

The tests were conducted in three phases. The first phase tested the feedwater line in its as-built configuration, in which vertical hangers and springs supported the piping—an old piping system design approach of the early 1960s. The second phase removed the piping insulation and retested the system. The third phase modified and refitted the as-built piping with the stiffer support configurations of modern design schemes. Four support configurations incorporating various types of snubbers and strut support arrangements were tested.

The in situ tests were completed early in 1981. A large data base generated for each configuration showed the results of both forced vibration and transient snapback tests at various load excitation levels. In-depth evaluation and analysis of test data followed. EPRI reports NP-1505 and Vol. 1 of NP-3108 document the results of the test and analysis. Results from additional data evaluation will be published in Vol. 2 of NP-3108 in 1984.

One of the major outcomes of this project was that test results indicated average measured damping values for the system were 2–4%, which is consistently higher than the 1% value specified in NRC Regulatory Guide 1.61 for an 8-in (20-cm) line at OBE levels (Figure 1). EPRI has submitted the entire damping data set to the PVRC piping systems technical committee as its contribution to an industrywide data base that supports a more-realistic damping guideline for nuclear piping design and analysis.

On the basis of more than 20 data groups supplied by various industry and government organizations (EPRI's Indian Point-1 data group was one), the PVRC piping committee recently proposed a new piping damping guideline, as shown in Figure 1. In general, the actual piping damping is system dependent. The PVRC proposed damping is regarded as a best-estimate representation of a widely scattered data base (from less than 1% of critical to more than 20% of critical). Studies have shown that use of the PVRC damping guideline would lead to a significant reduction in piping response—up to 40 or 50%. Such response would result in fewer supports and/or snubbers required in piping design.

In the particular feedwater line tested, the system damping was insensitive to both insulation and response levels below piping yield. In estimating damping from data, researchers found that damping in terms of energy dissipation derived directly from response amplitude decay of time history traces (the logarithmic decrement approach) is more appropriate for a slightly nonlinear system, such as the one tested. Another method of estimating damping, one based on the energy band in a frequency domain (the half-power bandwidth approach), may significantly overestimate the system damping in such situations.

Seismic evaluation of multiple-support piping

Design of a nuclear plant piping system often requires that supports be installed in various building structures, as well as at different floor elevations. During a seismic event the piping system supports would undergo earthquake-induced motions of different magnitudes and characteristics. This phenomenon, called multiple-support excitation, has long been a challenge to analysts who must predict piping seismic responses.

Current industry practice employs a conservative approach and assumes all supports are synchronized to respond to an input load that is the envelope of all the calculated excitation input at each individual support. Although this approach is simple and cost-effective, it often leads to an overly conservative and hence inefficient piping design.

Researchers have developed and proposed several improved methods to assess the impact of multiple-support excitation, but lack of actual seismic response data and the uncertain nature of the support correlation have prevented the improved methods from fully qualifying for design and licensing acceptance. To overcome this problem, EPRI initiated a multiple-support piping seismic evaluation project (RP964-8) with the objectives of establishing an experimental data base for method qualification and adding to the knowledge on multiple-support piping seismic characteristics. Under this project researchers conducted a series of seismic shake table tests at UCB's Earthquake Engineering Research Center. The tests involved attaching the piping system to two supporting frame structures at various floor elevations and then subjecting the combined system model to a variety of earthquake excitations, including both historical and artificial records at different magnitudes.

Broad-base response data were recorded. Preliminary results indicated a considerable piping-support coupling effect; this could be attributed to the small difference between the fundamental frequencies of the piping system (5.2 Hz) and the support structures (5.4 and 3.8 Hz). An EPRI report is being prepared that will assess the test measurements. Continuing efforts in 1984 will apply the test data to the problem of method qualification.

In conjunction with the experimental work, researchers at UCB developed an improved method of analysis that gave special consideration to the support correlation. The method, based on random vibration and the floor response spectrum concept, defined the correlation between model responses and various support points through cross-oscillator, cross-floor spectra. Simple examples have demonstrated the validity of the method. Actual plant piping application, however, will require further assessment through a test correlation.

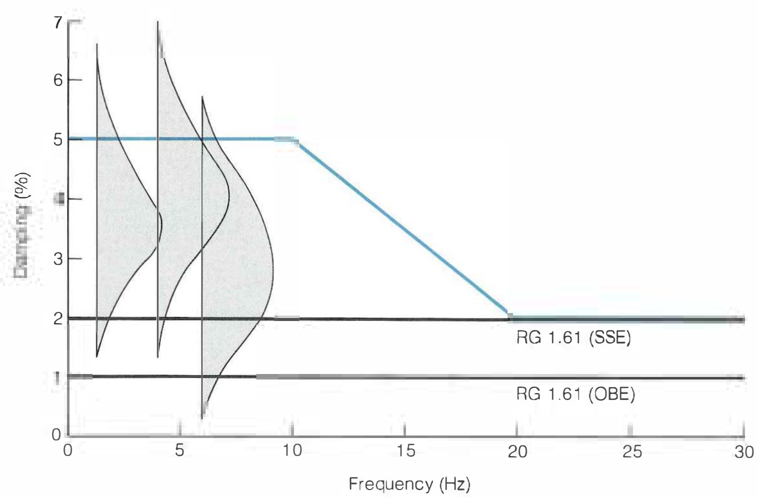


Figure 1 Comparison of Indian Point-1 measured damping (shaded areas) with Regulatory Guide 1.61 (gray rules) and the PVRC recommendation (color rule). The distribution of the measured damping indicates 4% of the data points are below 1% damping; 15% are below 2% damping. The PVRC recommendation is based on the best estimate of 21 data groups supplied by industry and government organizations, including Indian Point-1 data.

Dynamic capacity of piping and supports

The ASME Boiler and Pressure Vessel Code imposes conservative design standards for nuclear piping systems subject to dynamic loads (such as earthquake and water hammer). The ASME code bases its stress limits on ductile failure under statically applied loads. The margin against ductile failure is often much greater for a dynamic load than for a static load of equal magnitude, but so far very little data are available to quantify the dynamic failure margins of nuclear piping systems.

To increase the understanding of this area, EPRI initiated a project to conduct high-load amplitude piping dynamic tests at Anco's test laboratory (RP964-3, -9). The main objective of the research was to establish an experimental data base with which to assess the dynamic margin and failure capacities of a piping and support system. Test data were also intended for piping damping evaluation and for analytic method benchmarking.

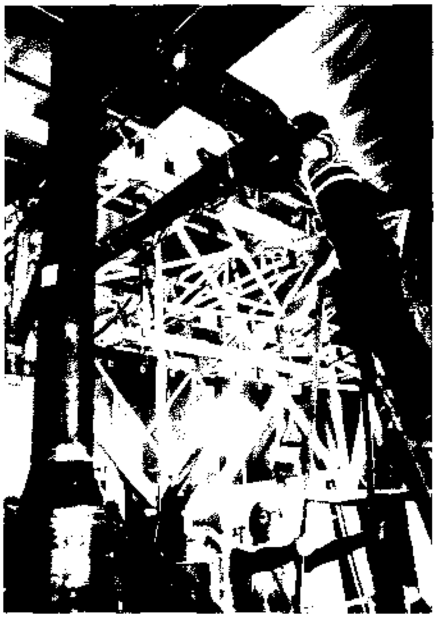
The test series started with a simple 22-ft-long, 4-in-diam (7-m, 10-cm), Z-shaped piping system supported at three locations. Various support hardware, including rigid struts and both mechanical and hydraulic snubbers, were installed at midsupport location. The piping was internally pressurized to 1100 psig (7.6 MPa) for each test series. Hydraulic actuators sent input motions through the support points to excite the system beyond its design-allowable limit.

Test results from this simple system proved that design of a piping and support system can allow for a large dynamic margin. The pressurized pipeline showed no leakage or plastic collapse after a sustained seismic load during which input magnitude rose as high as 16.0 g and piping material stretched beyond yield. Test results also indicated that the ultimate load capacity of snubber support could be four or five times higher than the manufacturer-specified value; for instance, a mechanical snubber failed at 1900 lbf (8.45 kN), compared with a specified maximum of 500 lbf (2.2 kN).

Research effort to conduct laboratory-based dynamic tests on more-complex piping systems has continued with NRC's participation. Two test configurations were designed and fabricated in compliance with ASME Class 2 nuclear piping specifications. One configuration consisted of a 10-elbow, three-dimensional, 6-in-diam (15-cm) pipe without branch lines (Figure 2), and the other consisted of a similar 6-in-diam main run with two 3-in-diam (7-cm) branch lines. All lines were pressurized up to 2000 psig (13.9 MPa) at room temperature and tested with simultaneous dynamic forcing input at all supports. Anco upgraded its test facility to excite these heavier piping systems to levels beyond the allowable stress limit.

Testing the first line has been completed. Preliminary results indicated that the system operated without any apparent damage when subjected to earthquake input four times larger than that deemed tolerable by the design code rules. Preliminary evaluation of the test data also indicated that the piping system damping was in the neighborhood of 2–3% at lower load magnitudes and 3–5% at higher load magnitudes.

Figure 2 Erection of the first high-magnitude piping test specimen of the EPRI–NRC joint research project at Anco Engineering's test laboratory.



An experimental data base will be generated after the completion of the second line test, which is scheduled in the first quarter of 1984. EPRI will transmit reports of the final results to the PVRC Piping System Committee in support of the effort to establish more-realistic piping design requirements in damping and dynamic stress limits. *EPRI Project Manager: Y. K. Tang*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1196-4	Steam Turbine and Rotary Separator–Turbine Test	4 months	34.9	Barber-Nichols Engineering, Inc. *E. Hughes*
RP1590-3	DAF-500 Wind Turbine Test Program	23 months	200.0	Southern California Edison Co. *F. Goodman*
RP1989-2	Cost Estimates for Vertical-Axis Wind Turbines	1 year	200.0	Bechtel Group, Inc. *S. Kohan*
RP2003-5	Solar Parabolic Dish–Stirling Engine Evaluation	16 months	223.1	Department of Energy *R. Taylor*
RP2029-7	Comparison of Two Coal-Based Power Generators: IGCC Coal-Fired Steam	14 months	662.4	Bechtel Group, Inc. *A. Lewis*
RP2049-7	Survey on Repowering of Existing Steam Turbine Plants	3 months	29.6	A. C. Kirkwood & Associates *H. Schreiber*
RP2052-2	Feasibility of Advanced Steam Systems for Combined-Cycle Power Plants	23 months	125.0	Bechtel Group, Inc. *A. Cohn*
RP2102-2	Combustor Viewing Systems for Industrial Gas Turbines	3 years	518.6	United Technologies Research Center *L. Angello*
RP2302-2	Molten Salt Thermal-Electric Experiment: Test and Evaluation	14 months	250.0	McDonnell Douglas Astronautics Co. *E. DeMeo*
RP2477-1	Advanced Power Cycles: Screening Evaluation	16 months	320.0	Fluor Engineers, Inc. *B. Louks*
RP2529-1	New Catalyst Systems for Coal-Derived Liquids	16 months	240.0	Brookhaven National Laboratory *N. Hertz*
RP2531-1	Improved Maintainability for Advanced Gas Turbines	7 months	155.1	Dow Engineering Co. *C. Dohner*
Coal Combustion Systems				
RP1861-1	Guidelines for Cofiring Refuse-Derived Fuels in Utility Boilers	2 years	200.0	Midwest Research Institute, Inc. *C. McGowin*
RP1865-3	Electromagnetic Acoustic Transducer System for Measuring Boiler Tube Wall Thickness	13 months	134.8	Materials Engineering Associates, Ltd. *J. Scheibel*
RP1865-4	Infrared Detection of Flaws in Boiler Tubes	8 months	68.9	Nondestructive Engineering Corp. *J. Scheibel*
RP1871-10	Corrosion Inhibitors for FGD Systems	13 months	329.0	La Que Center for Corrosion Technology, Inc. *B. Syrett*
RP1871-11	Characterization of Ceramic Material for Power Plant Operations	16 months	105.0	Ohio State University *R. Rhudy*
RP1871-12	FGD Rubber Liner Guidelines	17 months	92.4	Radian Corp. *C. Dene*
RP1895-8	Estimates for Coal-Water Slurry Utility Boiler Test	1 year	424.0	Burns and Roe, Inc. *R. Manfred*
RP1957-4	Flexible Eddy-Current Coil Arrays for Turbine NDE	9 months	98.2	Failure Analysis Associates *J. Scheibel*
RP2154-5	1985 Joint Symposium on Stationary Combustion NO_x Control	25 months	32.7	Acurex Corp. *M. McElroy*
RP2154-6	Overfire Air NO_x Control: Design and Operating Guidelines	19 months	448.5	KVB, Inc. *D. Eskinazi*
RP2214-2	Advanced Cooling-Water Intake Technology	8 months	51.8	Stone & Webster Engineering Corp. *J. Bartz*
RP2533-1	Dry Sorbent Emission Control Process Development	16 months	1436.1	Southern Company Services, Inc. *M. McElroy*
RP2534-1	Limestone Dual-Alkali FGD Pilot Plant Operation	15 months	325.8	FMC Corp. *T. Morasky*
RP2543-2	Design Alternative Analysis for AFBC Demonstration Plant	4 months	33.1	Decision Focus, Inc. *W. Howe*
RP2578-1	Five Year Plan for Power Plant Constructibility R&D Program	4 months	76.9	Sargent & Lundy Engineers *D. Golden*
Electrical Systems				
RP1289-3	Transformer Overload Characteristics	28 months	829.7	Westinghouse Electric Corp. *E. Norton*
RP1360-7	Gas-Insulated-Substation Participation Agreement	2 years	100.0	Ontario Hydro *V. Tahiliani*
RP1999-7	Intelligent Aids for Power System Operation: Assessment of Opportunities	1 month	50.0	Carnegie-Mellon University *M. Pereira*
RP2028-5	Formation of PCDD and PCDF in Askarel and Contaminated Mineral Oil Equipment	15 months	178.7	Radian Corp. *G. Addis*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2028-6	Formation of PCDD and PCDF in Askarel and Contaminated Mineral Oil Equipment	15 months	222.6	Battelle, Columbus Laboratories *G. Addis*
RP2028-7	Formation of PCDD and PCDF in Askarel and Contaminated Mineral Oil Equipment	15 months	92.8	New York State Department of Health *G. Addis*
RP2028-9	Formation of PCDD and PCDF in Askarel and Contaminated Mineral Oil Equipment	15 months	70.1	ITT Research Institute *G. Addis*
RP2205-1	Development of a Dry-Type Shunt Capacitor	32 months	638.9	General Electric Co. *H. Songster*
RP2323-1	Insulation Coordination in HVDC Converter Stations	2 years	199.5	General Electric Co. *V. Tahiliani*
RP2331-1	Detection of Open Rotor Bars in Motors	20 months	650.0	General Electric Co. *D. Sharma*
RP2336-1	Integration of Dispersed Storage and Generation Into Power System Control During Normal System Operations	30 months	391.9	Systems Control, Inc. *C. Frank*
RP7856-2	EPRI Underground Obstacle Mapping System: Training and Support Services	6 months	29.9	Ohio State University Research Foundation *T. Rodenbaugh*
RP7897-2	Development of Analytic Techniques for Insulation Characterization	26 months	420.0	Institute de Recherche de l'Hydro-Quebec *B. Bernstein*
RP7898-1	Measuring the Effects of Fast Switching Transients in Gas-Insulated Substations	5 months	28.9	Mississippi State University *V. Tahiliani*

Energy Analysis and Environment

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1630-40	Western Precipitation Chemistry	6 months	291.2	Battelle, Pacific Northwest Laboratories *D. Lawson*
RP1633-6	Compensation Mechanisms in Fish Populations	28 months	868.9	Science Applications, Inc. *J. Mattice*
RP1808-4	BENCHMARK Computer Program	4 months	56.4	Commonwealth Research Corp. *J. Delson*
RP1826-14	Cost-Benefit-Risk Assessment Methodology for Biofouling Control Alternatives	14 months	158.7	Ecological Analysts, Inc. *P. Ricci*
RP2069-5	Public Perception of Transmission Lines	26 months	99.7	Decision Research *A. Silvers*
RP2071-2	Materials Damage Due to Acidic Deposition	1 year	35.0	Brookhaven National Laboratory *R. Wyzga*
RP2141-7	Critical Assessments in Current Carbon Dioxide Research	15 months	150.0	Oak Ridge Associated Universities *D. Fromholzer*
RP2337-1	Lake Acidification Mitigation	41 months	1860.0	General Research Corp. *R. Kawaratani*
RP2340-1	End-Use Forecasting Model for the Agricultural Sector	22 months	197.3	Minimax Research Corp. *J. Chamberlin*
RP2346-1	Fisheries and Lake Acidification	61 months	1985.8	University of Wyoming *J. Mattice*
RP2369-20	Fuel Forecast Review and Analysis	13 months	122.5	Putnam, Hayes & Bartlett, Inc. *H. Mueller*
RP2373-1	Exposure to Respirable Particulate Matter	7 months	87.3	Geomet Technologies, Inc. *C. Young*
RP2391-2	Coal Combustion By-Product Disposal Issues: Scoping Study	2 months	30.0	Decision Focus, Inc. *V. Niemeyer*
RP2434-2	Massive Aerometric Tracer Experiment: Feasibility and Design Studies	14 months	1263.3	Environmental Research & Technology, Inc. *R. Patterson*
RP2434-3	Technical Services to Environmental Physics and Chemistry Program	1 year	136.4	Barad Consultants, Inc. *G. Hilst*
RP2485-1	Solid Waste Environmental Studies: Technical Management	51 months	1659.9	Tetra Tech, Inc. *I. Murarka*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP255-9	BEST Facility Operations	15 months	1448.6	Public Service Electric and Gas Co. *W. Spindler*
RP1085-10	Internal Reforming Molten Carbonate Fuel Cell Technology	3 months	103.3	Institute of Gas Technology *J. Appleby*
RP1086-16	Development of Photoelectrochemical Devices	11 months	70.0	Texas A&M Research Foundation *B. Mehta*
RP1745-13	Hydro/Storage Strategic Planning	10 months	59.1	Decision Focus, Inc. *J. Birk*
RP1966-4	Industrial Applications for Adjustable-Speed Drives	3 months	159.6	J. E. Sirrine Co. *R. Ferraro*
RP2033-19	Bivalent Heat Pump: Performance Evaluation	5 months	26.1	ETL Testing Laboratories, Inc. *J. Calm*
RP2344-1	Development of Internal Reforming Molten Carbonate Fuel Cell	4 years	3472.9	Energy Research Corp. *J. Appleby*
RP2376-1	Evaluation of Multizone and Central Electric Heating and Cooling Systems	9 months	210.0	Applied Management Systems *C. Hiller*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Nuclear Power				
RP893-3	Long-Term Evaluation of Fire-Retardant Fluid Lubricants	6 months	646.9	Westinghouse Electric Corp. *J. Matte*
RP1543-13	Application of Dynamic Fracture Mechanics to Pressurized Thermal Shock Problem	5 months	27.5	Southwest Research Institute *T. Griesbach*
RP1580-8	Creep Studies of UO_2 With Cation Dopants	22 months	73.7	Alfred University *S. Gehl*
RP1757-28	Alternative Weld Repair Procedure: Technology Transfer	1 year	31.5	Central Electricity Generating Board (England) *R. Nickell*
RP1935-5	Development of Cobalt-Free Hardfacing Alloys for Nuclear Applications	3 years	375.2	AMAX of Michigan, Inc. *H. Ocken*
RP2006-11	Local Power Range Monitors as Detectors of Stress Corrosion Cracking	13 months	69.6	Structural Integrity Associates *D. Cubicciotti*
RP2135-13	ANS Source Term Study	7 months	40.0	American Nuclear Society *F. Rahn*
RP2166-5	Program for Preventing and Mitigating Heat Stress for Nuclear Power Plant Workers	23 months	195.8	Westinghouse Electric Corp. *J. O'Brien*
RP2227-5	Small-Bore Piping Supports: Optimization Evaluation	6 months	32.5	Consumers Power Co. *R. Nickell*
RP2228-1	Nuclear Fuel Industry Program	30 months	100.0	Taiwan Power Co. *A. Machiels*
RP2233-2	Valve Motor Operator Improvements	23 months	464.8	Foster-Miller, Inc. *B. Brooks*
RP2233-3	Valve Stem Packing Improvements	7 months	454.7	Foster-Miller, Inc. *B. Brooks*
RP2293-1	BWR Water Chemistry: Impurity Studies	43 months	1745.2	Aktiebolaget ASEA–Atom *D. Cubicciotti*
RP2353-2	Application of Two-Fluid Steam Generator Code ATHOS–TF	11 months	80.3	Jaycor *G. Srikantiah*
RP2392-1	Modeling of Fuel/Coolant Thermohydraulics	11 months	70.7	Northwestern University *D. Squarer*
RP2394-9	Technical Framework for Implementing the Integrated Living Schedule Concept	3 months	32.2	Delina Corp. *G. Sauter*
RP2404-3	LOFT Analyses With the Modular Modeling System	11 months	79.9	Jaycor *M. Divakaruni*
RP2414-2	Chemical Preconditioning of Liquid Radwaste	21 months	100 0	Duke Power Co. *M. Naughton*
RP2429-1	Hybrid LMFBR System Concept: International Evaluation	7 months	100.3	Stone & Webster Engineering Corp. *D. Gibbs*
RP2430-17	Large-Scale Prototype Breeder: In-Service Inspection of Vessel and Internals, Plug Seal Maintenance, and Piping Reliability	10 months	218.0	Rockwell International Corp. *D. Gibbs*
RP2430-24	International and Fuel Cycle Planning	3 months	31.3	Westinghouse Electric Corp. *D. Gibbs*
RP2453-2	Pathways for Iodine and Iodine Compounds Through Steam Generators in a Simulated Tube Rupture Accident	23 months	100.1	Northwestern University *S. Kalra*
RP2493-1	PWR Chemistry: Cobalt Deposition	9 months	56.4	NWT Corp. *C. Wood*
RP2507-2	Enhancement of System Analysis and Reliability Assessment Network Software	4 months	25.1	Charles Horne *B. Chu*
RP2515-1	Robotics in Construction and Maintenance	3 years	300.0	Carnegie-Mellon University *M. Kolar*

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ADVANCED POWER SYSTEMS

Evaluation of U.S. Coal Performance in the Shell Coal Gasification Process
AP-2844 Final Report (RP2094-1); Vol. 1, $11.50; Vol. 2, $13.00
Contractor: Shell Oil Co.
EPRI Project Manager: G. Quentin

Early Utility Experience With Wind Power Generation
AP-3233 Final Report (RP1590-1); Vol. 1, $8.50; Vol. 2, $13.00; Vol. 3, $14.50
Contractor: JBF Scientific Corp.
EPRI Project Manager: F. Goodman, Jr.

Westinghouse 3.5-MW Magnetohydrodynamics Inverter: Design, Fabrication, and Systems Tests
AP-3303 Final Report (RP642-2); $28.00
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: R. Ferraro

User's Guide for the UNIRAM Availability Assessment Methodology
AP-3305-CCM Computer Code Manual (RP1461-1); $16.00
Contractor: Arinc Research Corp.
EPRI Project Manager: J. Weiss

Evaluation of Wet Oxidation Technology for the Treatment of Coal Conversion Wastewater
AP-3315 Final Report (TPS82-644); $13.00
Contractor: Olympic Associates Co.
EPRI Project Manager: W. Reveal

Photovoltaic Power Systems Research Evaluation: Report of the EPRI Ad Hoc Photovoltaic Advisory Committee
AP-3351 Final Report (RP1348-15); $11.50
Contractor: Strategies Unlimited
EPRI Project Manager: E. DeMeo

Proceedings: Eighth Annual EPRI Contractors' Conference on Coal Liquefaction
AP-3366-SR Special Report; $50.50
EPRI Project Manager: H. Lebowitz

COAL COMBUSTION SYSTEMS

Turndown Studies for Utility Fluidized-Bed Boilers
CS-3237 Final Report (RP1179-9); $10.00
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EPRI Project Manager: C. Aulisio

Evaluation of Electrostatic Precipitator Performance at San Juan-1
CS-3252 Final Report (RP780-1); $17.50
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EPRI Project Managers: R. Hooper, R. Carr

Optimization of Natural Gas Use for Ignition and Flame Stabilization in Coal-Fired Boilers
CS-3269 Final Report (RP1266-22); $8.50
Contractor: Foster Wheeler Energy Corp.
EPRI Project Manager: J. Dimmer

Failures and Inspections of Fossil-Fuel-Fired Boiler Tubes: 1983 Conference and Workshop
CS-3272 Proceedings (WS82-101); $41.50
Contractor: Aptech Engineering Services, Inc.
EPRI Project Manager: A. Armor

Manual on Chemical Cleaning of Fossil-Fuel-Fired Steam Generation Equipment
CS-3289 Final Report (RP1608-1); $44.50
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EPRI Project Manager: J. Dimmer

Testing and Correlation of Fly Ash Properties With Respect to Pozzolanic Behavior
CS-3314 Final Report (RP1260-26); $10.00
Contractor: University of California at Berkeley
EPRI Project Manager: D. Golden

Evaluation and Status of Flue Gas Desulfurization Systems
CS-3322 Final Report (RP982-28); $49.00
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EPRI Project Manager: D. Stewart

Calcium-Based Sorbent Requirements for Pressurized Fluidized-Bed Combustion Systems
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EPRI Project Manager: S. Drenker

Evaluation of Ceramic Fiber Filters for Hot Gas Cleanup in PFBC Power Plants: Phase 2 Results
CS-3331 Topical Report (RP1336-1); $10.00
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: S. Drenker, O. Tassicker

Investigation of Ammonium Sulfate Conditioning for Cold-Side Electrostatic Precipitators
CS-3354 Final Report (RP724-2); Vol. 1, $11.50; Vol. 2, $13.00
Contractors: Southern Research Institute; Stearns-Roger Engineering Corp.
EPRI Project Manager: R. Altman

Comparison of Alternative Methods for Measuring Cooling-Tower Drift
CS-3355 Final Report (RP1260-11); $29.50
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EPRI Project Manager: J. Bartz

Coal-Water Slurry Technology Development: Burner Technology
CS-3374 Final Report (RP1895-4), Vol. 1; $20.50
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EPRI Project Manager: R. Manfred

Feasibility and Design of Proposed Nashville Refuse-Fired Cogeneration Facility
CS-3377 Final Report (RP2190-1); $16.00
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ELECTRICAL SYSTEMS

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EL-3154 Final Report (RP1357-1); $14.50
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EPRI Project Manager: J. Mitsche

Current Fossil Fuel Power Plant Performance Monitoring: Practices
EL-3339 Final Report (RP1737-2), Vol. 1; $16.00
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EPRI Project Manager: J. Lamont

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EPRI Project Manager: H. Songster

ENERGY ANALYSIS AND ENVIRONMENT

Analysis of Power Plant Construction Lead Times
EA-2880 Final Report (RP1785-3); Vol. 1, $13.00; Vol. 2, $28.00
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EPRI Project Manager: S. Chapel

Operational Validation of Gaussian Plume Models at a Plains Site
EA-3076 Final Report (RP1616-1); $19.00
Contractors: Systems Applications, Inc.; TRC Environmental Consultants, Inc.
EPRI Project Manager: G. Hilst

Diagnostic Validation of Plume Models at a Plains Site
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Demonstration of TELPLAN Model: Union Electric Company Case Study
EA-3327 Final Report (RP1318-1); $8.50
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EPRI Project Manager: D. Geraghty

Workshop Proceedings: Effects of Trace Elements on Aquatic Ecosystems
EA-3329 Proceedings (RP1631); $29.50
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Aesthetic Considerations and Electric Utilities: An Introductory Guide to the Literature
EA-3386 Final Report (RP2069-4); $11.50
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EPRI Project Manager: S. Feher

Choice of Discount Rates in Utility Planning: Critique of Conventional Betas as Risk Indicators for Electric Utilities
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Survey of Conditional Energy Demand Models for Estimating Residential Unit Energy Consumption Coefficients
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EPRI Project Manager: S. Braithwait

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Impact of Industrial Robots on Electric Loads in U.S. Industry
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EPRI Project Manager: J. Brushwood

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EPRI Project Manager: V. Rabl

Performance Comparison of Air- and Ground-Coupled Heat Pump Systems
EM-3408 Final Report (RP1191-6); $11.50
Contractor: Oklahoma Gas and Electric Co.
EPRI Project Manager: G. Purcell

NUCLEAR POWER

THEDA-2: A Multidimensional Steam Generator Thermal-Hydraulic Model
NP-3031-CCM Computer Code Manual (RPS156); Vol. 1, $19.00; Vol. 2, $17.50; Vol. 3, $22.00
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: D. Steininger

Rationale for Chemical Control of Feedwater and Boiler Water: Concentration Models
NP-3048 Final Report (RP1171-1), Vol. 1; $11.50
Contractor: Central Electricity Research Laboratories (England)
EPRI Project Managers: M. Angwin, R. Varsanik

Determination and Verification of Required Water Chemistry Limits: Pot Boiler Tests
NP-3274 Final Report (RPS111-1), Vol. 3; $17.50
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: M. Angwin

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NP-3275 Final Report (RPS157-1); Vol. 4, $14.50; Vol. 5, $25.00
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EPRI Project Manager: M. Angwin

An Approach to the Assurance of Technical Adequacy in Probabilistic Risk Assessments of LWRs
NP-3298 Interim Report (RP2171-2); $11.50
Contractor: Energy Incorporated
EPRI Project Manager: D. Worledge

Physically Based Regression Correlations of Embrittlement Data From Reactor Pressure Vessel Surveillance Programs
NP-3319 Final Report (RP1240-1); $11.50
Contractors: Fracture Control Corp.; University of California at Santa Barbara
EPRI Project Manager: T. Marston

Pipe Cracking in PWRs With Low-Pressure Borated Water Systems
NP-3320 Final Report (RP1841-1); $11.50
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EPRI Project Managers: D. Cubicciotti, M. Fox

Digital Feedwater Controller for a BWR: Conceptual Design Study
NP-3323 Interim Report (RP2126-2); $19.00
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EPRI Project Manager: M. Divakaruni

Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components
NP-3326 Final Report (RP1707-4); $35.50
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EPRI Project Manager: G. Sliter

A Fundamental Equation Representing Water in Stable, Metastable, and Unstable States
NP-3328 Final Report (RP1438-2); $26.50
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EPRI Project Manager: G. Shugars

Stress and Fracture Analysis of Shrunk-On Steam Turbine Disks
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Contractor: Southwest Research Institute
EPRI Project Manager: M. Kolar

Metallurgical Evaluation of Keyway Cracking in Low-Pressure Turbine Disks
NP-3341 Final Report (RP1398-9); $13.00
Contractor: Southwest Research Institute
EPRI Project Manager: M. Kolar

Intergranular Stress Corrosion Cracking Surveillance System
NP-3352 Final Report (RPT104-2); $10.00
Contractor: Amdata Systems, Inc.
EPRI Project Manager: S. Liu

Commercial Aviation Experience of Value to the Nuclear Industry
NP-3364 Final Report (TPS82-670); $11.50
Contractor: Los Alamos Technical Associates, Inc.
EPRI Project Manager: D. Worledge

Identification of Radwaste Sources and Reduction Techniques
NP-3370 Final Report (RP1557-3); Vol. 1, $22.00; Vol. 2, $35.50; Vol. 3, $32.50
Contractor: Gilbert Associates, Inc.
EPRI Project Manager: M. Naughton

Study of Common Cause Failures: A Classification System
NP-3383 Interim Report (RP2169-1); $13.00
Contractor: Los Alamos Technical Associates, Inc.
EPRI Project Manager: D. Worledge

Nondestructive Evaluation Instrument Surveillance Test on 26-Inch Pipe

NP-3393 Final Report (RPT104-1); $11.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: M. Lapides

TRANSG-01: A Computer Code for Transient Analysis of Nuclear Steam Generators

NP-3394-CCM Computer Code Manual (RP684-1); Vol. 1, $14.50; Vol. 2, $10.00; Vol. 3, $14.50; Vol. 4, $10.00
Contractor: University of Michigan
EPRI Project Manager: S. Kalra

Evaluation of Computer-Aided Design and Drafting for the Electric Power Industry

NP-3398 Final Report (TPS82-649); $10.00
Contractors: Michigan Energy and Resource Research Association; Bechtel Power Corp.
EPRI Project Manager: M. Kolar

Criteria for Determining the Duration of Integrated Leakage Rate Tests of Reactor Containments

NP-3400 Final Report (RP1393-5); $13.00
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EPRI Project Manager: T. Law

Workshop on Corrosion Product Sampling From Hot Water Systems

NP-3402-SR Proceedings; $25.00
EPRI Project Manager: Y. Solomon

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NP-3406 Final Report (RPT101-4); $17.50
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EPRI Project Manager: S. Liu

Initial Examination of the Surface Layer of a 9-Inch Leadscrew Section Removed From Three Mile Island-2

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EPRI Project Manager: A. Roberts

Recovery of TMI-2 Reactor Building Polar Crane

NP-3411 Final Report (RP1544-8, -13); $19.00
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EPRI Project Manager: R. Winkleblack

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NP-3419 Interim Report (RP825-1); $11.50
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EPRI Project Manager: R. Shaw

Use of Safety Importance Rankings in Equipment Qualification: A Study of Big Rock Point

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EPRI Project Manager: R. Kubik

Verification and Validation of the Yankee Plant Safety Parameter Display System

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EPRI Project Manager: D. Cain

R&D STAFF

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EPRI Project Manager: R. Jaffee

Potential of Duplex Stainless Steels for Utility Applications

RD-3401 Final Report (TPS81-815); $13.00
Contractor: Battelle, Columbus Laboratories
EPRI Project Manager: R. Jaffee

TECHNICAL INFORMATION

Digest of Research in the Electric Utility Industry

Digest-83 Final Report, Vols. 2 and 3; $20.00 for two-volume set
EPRI Project Manager: P. Bates

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