Batteries for Utility Systems

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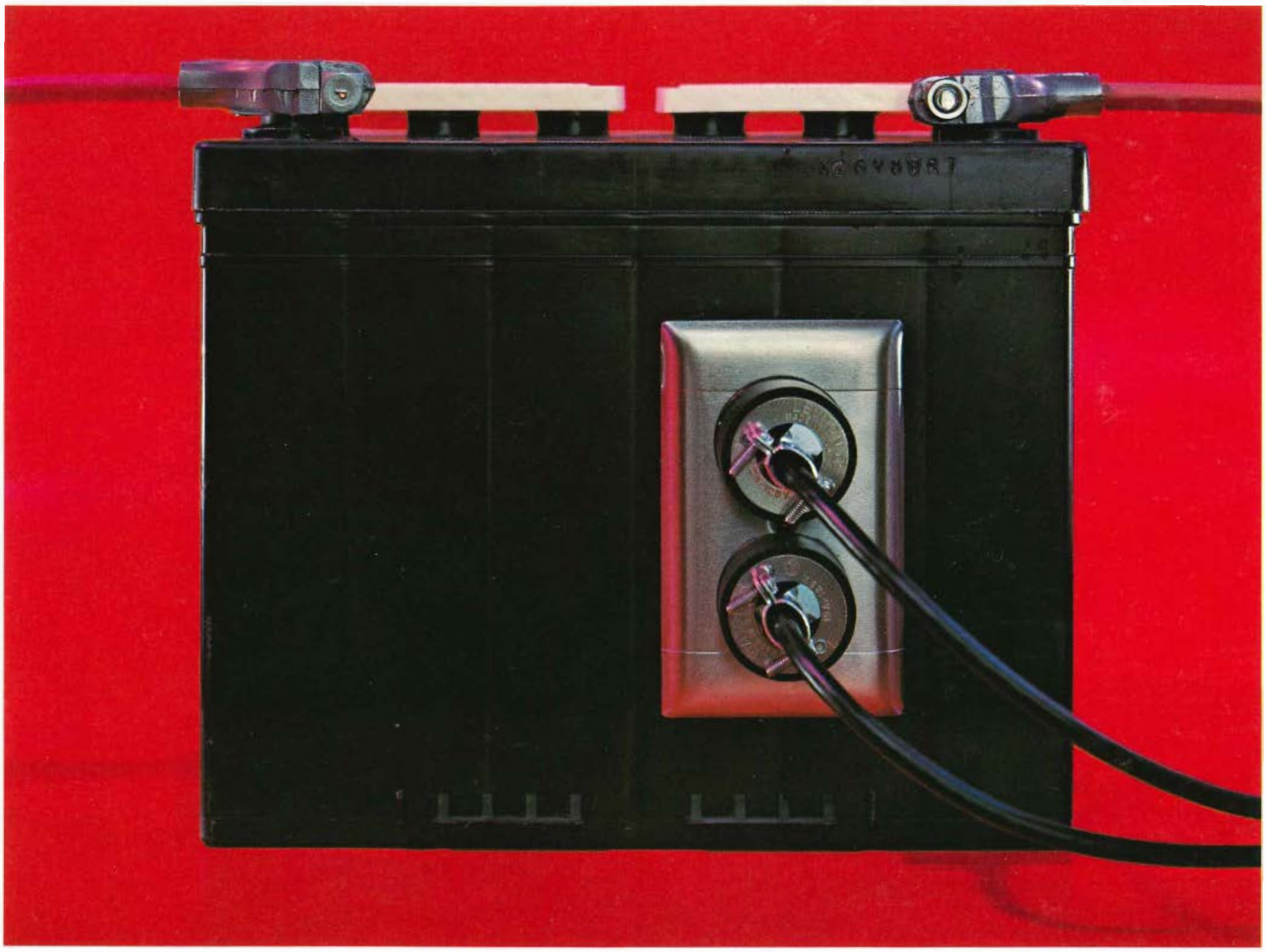

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COVER: Storage batteries are taking on a new look as the electric utility industry prepares to plug in.

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BEST: The Vital Step Toward Battery Energy Storage

Consider a ''super battery'' some 200,000 times larger than your car battery. This may be what electric utilities eventually use to store off-peak baseload energy for delivery during daily peak demand periods.

Installations of this size have never been built, even with familiar lead-acid types of batteries. They represent a still larger extrapolation of technology for the more promising, but much less developed, battery types that are the focus of EPRI-funded battery research reviewed in this month's state-of-the-art feature and in the FFAS R&D Status Report.

Advanced batteries have electrochemical, electrical, and thermal characteristics quite different from those of batteries that are commercially available. Putting a large system together and having it interact with an electric power network is certain to result in technical and operating problems that cannot be predicted from the behavior of laboratory models alone.

Late in 1973, as we began to structure a comprehensive EPRI program for development of utility batteries, we became convinced that testing prototype batteries under closely controlled conditions and in sizes and test models relevant to utility operation was necessary before this new technology could be demonstrated on utility systems without undue technical, financial, and safety risks. This need was discussed with our utility advisers. With their active assistance, we gained the interest of AEC (now ERDA), which had been considering a battery demonstration plant project. From this emerged the general concept of a national Battery Energy Storage Test (BEST) Facility and a specific agreement that the technical and cost feasibility of this concept should be studied seriously.

To do this, a BEST Facility project team was formed from utility personnel and staff members of Argonne National Laboratory and EPRI. Under the leadership of EPRI's Jim Beck and with information from battery developers, as well as from a facility design study by Bechtel, Inc., the team identified the key requirements and concluded a year ago that establishment of a BEST Facility was indeed feasible. Since then, EPRI and ERDA have agreed to jointly implement the concept.

In competitive bidding, New Jersey's Public Service Electric and Gas Company was selected as the prime contractor to design the facility and to construct it on a PSE&G substation site in Somerset County. If battery development and facility construction schedules mesh, in 1980 PSE&G should begin to test prototype batteries capable of storing up to 10 MWh of energy and delivering several MW into the power grid—at a testing facility that will be open to all promising battery systems.

The concept and study of the BEST Facility have already become major motivations for an in-depth dialogue between battery developers and funding agencies. Building the facility further emphasizes EPRI and ERDA's commitment to battery development, and the evaluation of prototype batteries should become a high point in that commitment. I firmly believe that some day the implementation and use of the BEST Facility will be recognized as a vital step on the road to practical batteries for utility energy storage.

Fritz R. Kalhammer

Fritz Kalhammer, Director
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Authors and Articles

What more obvious way is there for electric utilities to store energy than in batteries? Consider the advantages: Batteries could store energy when demand is low for use when demand is high. Batteries could be recharged at night, using cheaper baseload energy.

As the utility industry moves toward coal and nuclear fuels to power its baseload, batteries seem increasingly attractive. With battery-stored energy to meet daytime peaks, the least efficient, most costly oil-fueled generation can be replaced. Load-leveling operation with storage batteries thus will help utilities make the best use of their installed generating capacity and the most plentiful fuels.


Searl


Crow

▫ "Storage Batteries: The Case and the Candidates" (page 6) describes efforts now under way to develop long-lived, low-cost batteries for utilities. This state-of-the-art feature was prepared by JOURNAL feature editor Ralph Whitaker, with assistance from Jim Birk, manager of the battery energy storage subprogram for EPRI's Fossil Fuel and Advanced Systems Division.

▫ Development of energy storage systems is complemented by EPRI's studies of energy supply, a subject that has occupied Milton Searl during most of his professional career. In "Sensing the Energy Future" (page 14), the manager of EPRI's Energy Supply Program reviews his often esoteric task of predicting the energy future with analyses that bring into play both scientific interpretation and intuitive guesstimation. "So complex is the energy system," says Searl, "that it may not be possible to adequately represent all its elements. Nevertheless, the mission of EPRI's Energy Supply Program is to provide the Institute and the utility industry with careful analyses of the energy future."

Searl came to EPRI in 1973 from Resources for the Future, Inc., where he prepared, supervised, and consulted on studies of energy supply, including industry taxation, natural gas regulation, nuclear power growth, and solar energy. He drafted alternative energy supply scenarios for the Ford Foundation's Energy Policy Project in 1973. For three years, beginning in 1968, Searl was chief economist on the Energy Policy Staff of the U.S. Office of Science and Technology. Earlier, he was AEC's senior economist and staff representative on resources and supply for several studies on coal and uranium reserves, nuclear power costs, and energy R&D needs. Searl is a 1948 graduate in economics from the Illinois Institute of Technology.

▫ Another mechanism for more efficient use of electric energy is the heat pump. In "The Heat Pump: Renewing an Option" (page 20), Robert Crow and Joseph Pepper trace efforts to develop improved heat pump systems, measure their market potential, and determine their likely effects on daily and seasonal electric utility load curves. The authors cite the pros and cons of heat pumps from both the consumers'

Pepper

and the utilities' standpoints. Twelve utilities are participating in a joint EPRI–Association of Edison Illuminating Companies year-long field test to gauge heat pump performance and load characteristics, which involves 120 single-family dwellings in strategic locations throughout the country.

Robert Crow is manager of the Energy Demand and Conservation Program in the Energy Analysis and Environment Division. His major research interests are econometric demand analysis, regional growth, and the theory of consumer behavior. He came to EPRI in 1974 from the faculty of the School of Management, State University of New York at Buffalo, where he taught microeconomics, macroeconomics, regional growth and forecasting, and urban transportation planning.

As assistant director of economics and senior economist for Mathematica, Inc., from 1967 to 1970, Crow directed construction of econometric models of freight and passenger transportation and other studies. Earlier, he worked with the U.S. Department of Transportation as a regional economist for the northeast corridor transportation project. Crow has a doctorate in economics with a minor in regional science from the University of Pennsylvania.

Joseph Pepper is acting manager of the Energy Utilization and Conservation Technology Program of the Fossil Fuel and Advanced Systems Division. He joined EPRI in 1974 after earning a doctorate in mechanical engineering from Stanford University. He had previously received a masters in engineering science from Florida State University. Pepper has been an engineer for such firms as Pan American Oil in Lake Charles, Louisiana, and Buckeye Cellulose in Foley, Florida, as well as with NASA at Cape Kennedy and the Florida State Road Department.

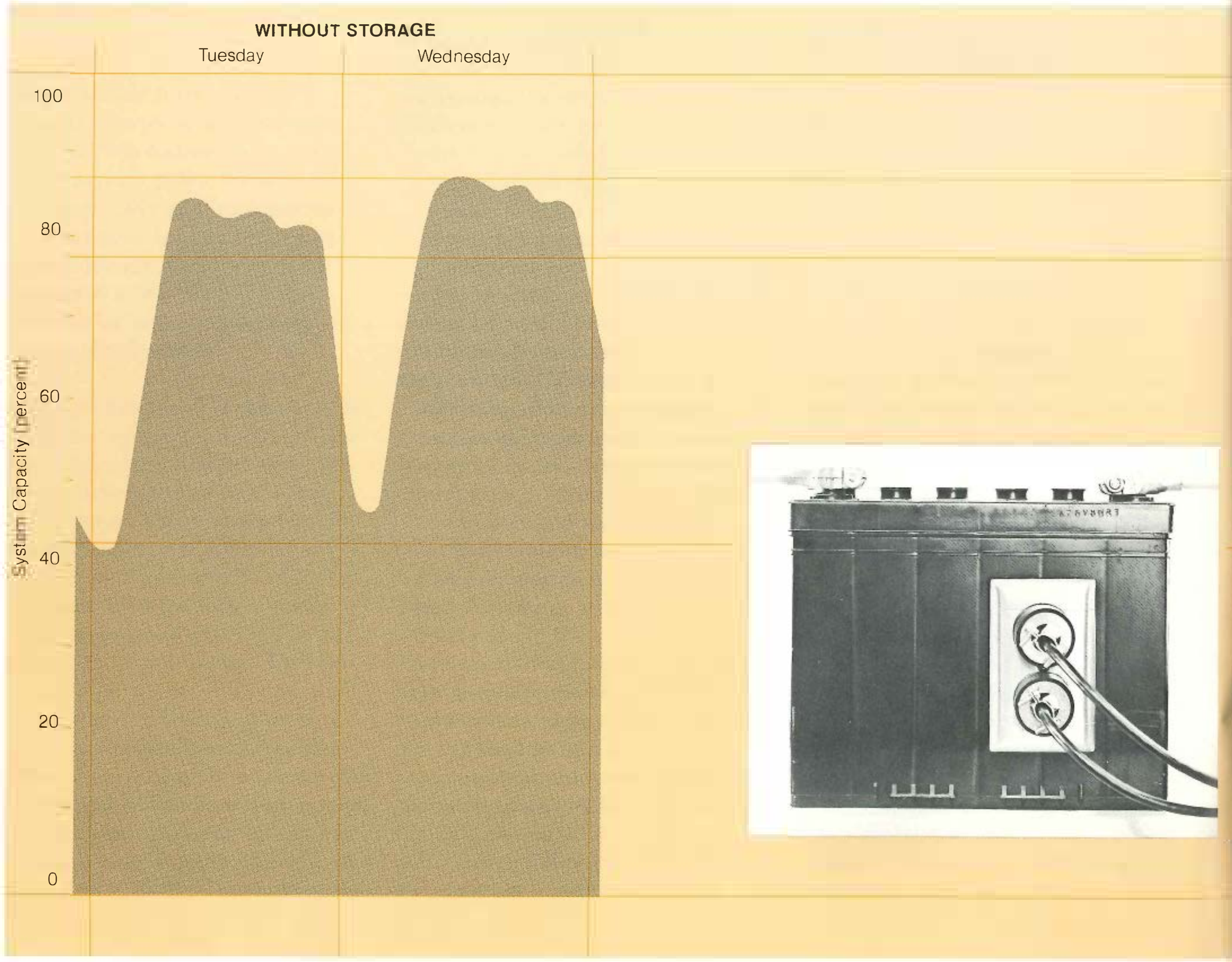
□ The series of JOURNAL interviews with EPRI Advisory Council members continues. For this issue, staff writer Stan Terra spoke with Thomas L. Kimball, executive vice president of the National Wildlife Federation.

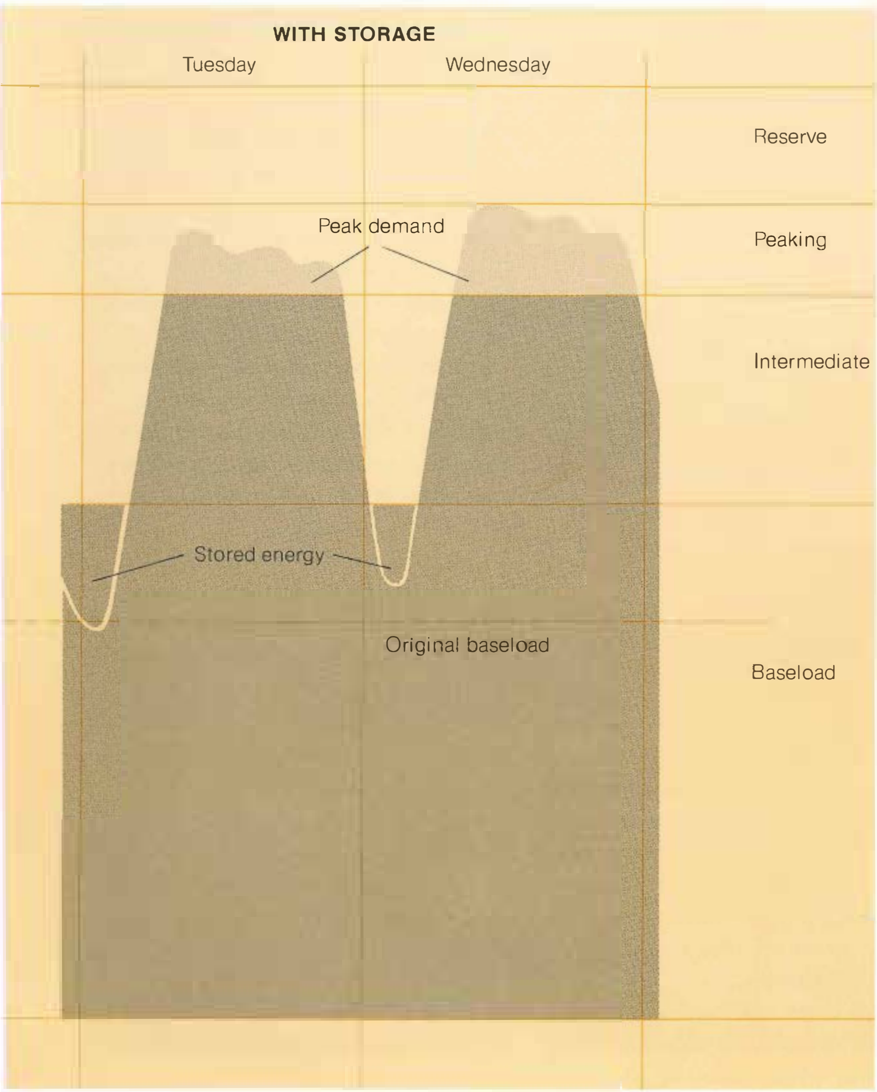
Storage Batteries: The Case and the Candidates

How can batteries help electric utilities? Can they really conserve fuel, or cut its cost? What special advantages do they offer? How much will they cost?

□ An EPRI state-of-the-art feature

Typical utility load curves show how a mix of generating capacity is used to meet demand, with and without energy storage. When batteries are introduced, the fuel-efficient baseload generators can run at a higher level around the clock. Not only does stored energy meet peak demand, but the need for intermediate generation is reduced. From a utility's standpoint, its generating requirement is thus more nearly level.





Generators thrum throughout the day to provide the electricity that powers U.S. industry and society. The problem is, those generators don't thrum at night when the demand for electricity ebbs. Thus an electric utility's need for generating capacity, not to mention transmission and distribution facilities, is measured by its daytime peak demand.

This circumstance calls urgently for a way to store electricity—if it existed, some happy medium in generating capacity that could satisfy off-peak demand and, at the same time, build up an energy inventory for use in peak hours.

This concept of load leveling is simple enough. And to a citizenry that starts its workdays and begins most of its weekends with an automobile ignition key, the answer is obvious: batteries.

But reality is more complex. For electric utilities it involves, at the very least, the trade-offs in capital and operating costs between battery energy storage and the oil-fired combustion turbines now most frequently used to drive "peakers," the generators that must be cut in for just the few hours each day when demand is highest.

For battery chemists, the reality of load-leveling batteries necessarily involves a new, more stringent set of performance, life, and cost requirements. It's more than simply building a Sears Diehard battery to heroic proportions.

How does storage help?

Even more basic is the concept of energy storage itself. Storage is important because it is the functional alternative to intermediate- and peak-demand generators and must compete with them economically as well.

For example, the familiar hydroelectric reservoir stores energy, even though today it is usually regulated to provide a steady, baseload flow of water through its turbines. But in recent years the same mechanism has also been adapted for storage and load leveling. Off-peak electric power from a fossil-fueled or a nuclear station is used to pump water up into a reservoir, from which it is later released to "shave" a peak.

Such hydro storage inevitably exacts a cost in the energy expended for pumping. But it yields offsetting savings in at least two ways: a reduction in the peak generating capacity (and its scarce, costly fuels) otherwise needed and a more consistent use of the economical, fuel-efficient baseload plant that furnishes the off-peak pumping power.

Does storage save fuel?

The question often arises whether energy storage enables true fuel conservation (a net saving) or simply a redistribution of fuel delivery timing. For the most part it is the latter, and this can be illustrated by comparing the approximate efficiencies of the equipment alternatives. Oil-fired combustion turbines, popular because of their low capital cost ($125/kW), have a typical efficiency of 24%. Baseload generators (up to $1200/kW), on the other hand, show efficiencies of about 38%. Storage systems—battery or pumped hydro—are about 75% efficient; so the combination of baseload and storage is about 28%, slightly better than gas turbines. The indicated 4% edge for baseload and storage is a rough average and therefore artificial; it is so close to a standoff that each system must be evaluated individually.

In terms of fuel energy content, net saving thus cannot be claimed unequivocally for storage. However, there is an almost assured opportunity to save certain types of fuel, notably oil, which is recognized to be scarce and has value other than as a thermal electric generator fuel—in the petrochemical industry, for example, not to mention in transportation.

Moreover, a switch in fuel type constitutes a distinct economic incentive for battery or other storage development. The fuel and operating costs for combustion turbines are 30–35 mills/kWh. For baseload generators used to "charge" storage, they are only about 15 mills/kWh.

Storage will also be the key to the success of electric utilities in making yet another fuel switch: extracting and using energy from natural dynamic resources—the sun, wind, and tides.

What do batteries offer?

The function of energy storage, together with the counterpoint of peaking generators, suggests the objectives batteries must meet to be competitive. Assuming that specific cost and performance criteria are met through continued R&D, batteries offer numerous benefits:

Functional Batteries are uniquely versatile and rapid in their response to electric system needs. Most obviously, they are intended for load leveling. Inherently instantaneous switching suits them also to the role of spinning reserve—the term applied to a standby generator kept idling and therefore able to respond to additional demand within minutes. Batteries are valuable for system regulation, compensating for momentary system load fluctuations from average demand. Finally, battery output can exactly match incremental changes in load (load following) with no efficiency penalty. By contrast, a peaking generator is most efficient at a single output and is less efficient at all other values of load demand.

Physical Made up from individual cells in factory-built modules, batteries afford many benefits. Battery storage can be installed anywhere that is suitable for a distribution substation of unobtrusive, conventional appearance. (Pumped hydro, by contrast, requires a dam site or even construction of an artificial reservoir.) This suggests dispersal of battery storage in ideally sized increments, permitting savings—or at least deferral—of transmission capacity. Such dispersal enhances system reliability because the power source and its load are thus close to each other. Further, the separate modules of storage are more reliable because a failure of one module, for whatever cause, leaves the others intact. Standardized, modular design also produces the benefit of a short lead time for manufacture, delivery, and installation, enabling a utility to select and add storage exactly as needed.

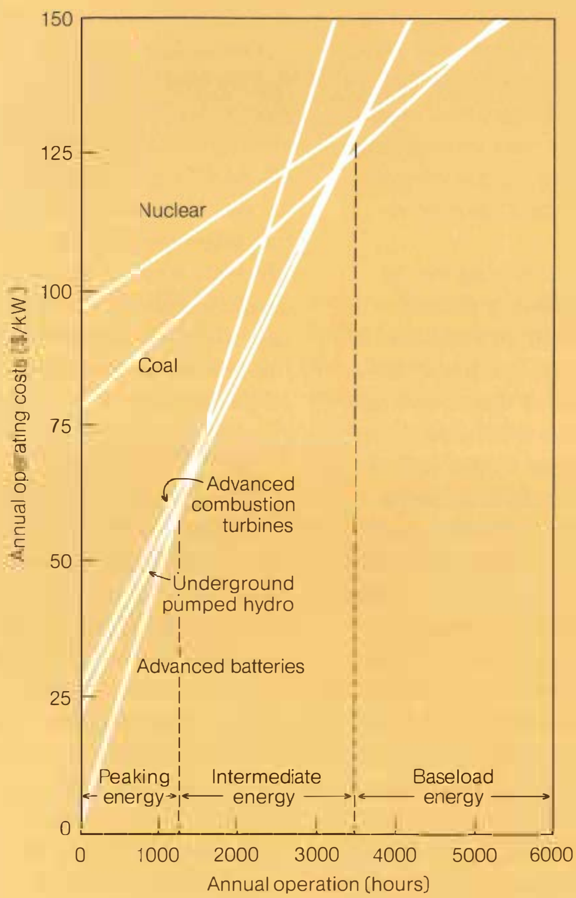
Environmental Batteries are unusually free of environmental problems, particularly in comparison with combustion turbines: little noise from cooling motors, negligible emissions, no vehicular traffic in fuel or wastes, no extensive excavation. The land requirement is modest: about one-half acre for a 20-MW, 100-MWh battery storage installation.

Why not batteries right now?

Given these many and obvious advantages, what prevents the immediate use of batteries for utility load leveling? The major obstacle is that today's batteries do not meet the standards of performance, life, and cost required for utility service: capability for deep discharge, capability for repetitive cycling, long life under these conditions, and low specific material cost (dollars per kilowatthour). This will take time and money to resolve.

Today's perception of the need for and desirability of battery storage is new. Until this decade, energy and electric power technologies were based, for all practical purposes, on the unlimited availability of cheap fuel: at one time wood, then coal, and more recently, the supremely convenient oil and natural gas. Without a utility industry market for batteries, there was no incentive to advance battery technology to meet the performance standards now developing among utilities, research groups, and manufacturers.

One mainstay of today's market is the nonrechargeable, or primary, The relative overall economy of different modes of power generation depends on annual hours of operation. Among the major options to be available in coming years, coal and nuclear plants, which have high capital costs to be defrayed, are cheapest when run 3500 hours or more. For the shorter periods of intermediate duty, advanced turbines and pumped hydro storage (charged with cheap off-peak energy from baseload plants) are more economical. For peaking service, battery storage has the additional advantage of low capital cost.



NEW FUNDING FOR SODIUM-SULFUR RESEARCH

The latest step in EPRI's research program on storage batteries is a $2.5 million contract awarded in July to the General Electric Company's Corporate Research and Development Center. Augmenting work already under way at GE, the 32-month effort is aimed at developing the sodium-sulfur battery into a full-scale building block for utility energy storage.

James Birk, EPRI's project manager for advanced batteries, puts it this way: "GE's goal for this phase of the program is to build and initiate testing of a 100-kWh battery module—roughly the size of an office desk. A complete storage system would involve little more than putting together an array of these modules to get whatever storage capacity is desired."

GE's battery operates at between 300 and 350°C, with a ceramic electrolyte of beta alumina (made up of sodium, aluminum, and oxygen), which separates the molten sodium and sulfur electrodes.

EPRI has supported this development since 1973, during which time technical feasibility has been demonstrated by solving most system performance problems. "A year ago it wasn't possible to get more than 50% utilization of cell storage capacity—what people sometimes call depth of discharge," says Birk. "Now the figure is consistently 85%.

"Also, cell life has been boosted to more than 8000 hours of continuous charge and discharge at rates that will be needed for electric utility applications. One important factor was improving the beta alumina so that it no longer limits battery life."

Work under the new contract will focus on further increases in battery life by selective improvement of components, particularly the seals that secure the system.

GE's present lab cells—each about 1" x 8"—can store 32 watt hours. Birk adds that considerable engineering design will be needed to scale the battery up to 100-kWh modules, each expected to employ 350 individual cells. "By 1981," he concludes, "we hope to have GE install and test 50 modules in a 5-MWh system at the Battery Energy Storage Test Facility that EPRI and ERDA are cosponsoring."

battery for one-shot, emergency service or for only occasional need or convenience over a long time—as in flashlights or radios. The chemical reactions that yield its electron flow are essentially irreversible, and relatively inexpensive active materials are suitable to its purposes.

The rechargeable, or secondary, storage battery is used most widely in automobiles. Other uses include prime power for industrial warehouse trucks, forklifts, and mine and tunnel locomotives; standby power for circuit breakers, communications switching, and lighting; and control system power for mass transit vehicles, spacecraft, and remote beacons and buoys. Right now, the largest-capacity (but highly specialized) secondary batteries are those manufactured for naval submarines. All these uses justify the more expensive materials needed for reversible operation: charge and discharge. But the cost of these materials (in either the type or the amount needed) is prohibitive for batteries used in electric utility systems.

Adaptation or advancement of battery technology for electric utility systems is thus a new and high-risk venture beyond the capability of manufacturers alone. A stair-step rather than a ramp of upgraded capacity and life, along with deep discharge capabilities and unimpaired reliability, is the task under way now, with R&D funding that approaches $15 million for this year alone and will probably total more than $125 million between 1977 and 1981.

What can utilities afford?

Beyond the R&D cost of achieving specific performance targets for batteries is the cost of the batteries themselves, not to mention the auxiliary inverters and other special apparatus making up a complete battery storage station. And there is the operating cost. These costs must compete with alternative storage or peak generating costs. The question becomes: What cost is affordable to electric utilities? The answer is not easy to find for two reasons. One is the value of capital cost credits that may be allowed to batteries because of the savings they permit elsewhere in a utility system, notably in T&D requirements avoided or deferred by dispersed battery storage.

The other reason is that battery storage capital cost is directly tied to the battery's intended hours of discharge. The size of a utility battery is meaningfully expressed as a capacity in kilowatt hours, not simply as a kilowatt rating. A combustion turbine can produce its rated power 24 hours a day throughout the year, so long as it is fueled. But a battery can produce its rated power for only a fixed time, say 2, 5, or 10 hours, depending on its design, and it must then be recharged.

This approach to costing can be illustrated by comparing gasoline- and battery-powered automobiles. A conventional automobile has a sticker price (or capital cost) that is independent of the mileage it is to be driven each day. So long as its gas tank is refilled (virtually instantaneously), the car can be driven continuously. A battery-powered electric automobile, on the other hand, is limited in range by the capacity of its batteries. To extend the range, they must be proportionately larger and more costly. And in no case do they permit continuous operation because of the time required for recharging. The sticker price (capital cost) of an electric vehicle, therefore, depends on its mileage range—in effect, on its planned duty or hours of use.

Assumptions of duty—numbers of cycles and their duration—must therefore be made to arrive at a specification for utility battery capacity. Applying known or estimated unit costs for materials and manufacturing labor to that specification yields a battery capital cost in terms of the specified kilowatt hours of capacity. Comparing that cost with the cost of competing generation alternatives requires calculations or estimates of their capital costs if spread over the same annual duty, or hours of operation. Such estimates have been made, and the corresponding operating costs (fuel, operation, and maintenance) have been added; the results are shown in the accompanying graph.

Assuming a $50/kW credit available, a so-called advanced battery storage system is the most economical alternative to other peaking or storage schemes up to 1200 or 1300 hours per year. Its annual cost of operation *at that point* is approximately $60/kW.

The battery, alone, for such a system is the principal R&D focus. System studies by EPRI have included breakeven cost analyses for batteries with 10- and 20-year lives and with 2-, 5-, and 10-hour discharges. The resultant target costs are shown in Table 1. The wide range of figures for each condition reflects numerous uncertainties, including probable variations in future costs of fuel and therefore of off-peak power to charge the batteries.

What will batteries cost?

Can these figures be matched by any battery today, or by any battery foreseen by the R&D community? Which ones, and why or why not?

Broadly speaking, two groups of secondary batteries are under consideration: those considered state of the art and those advanced types under development, with no track record.

Batteries are designated, not entirely consistently, by the elements or compounds used for their electrodes. The state of the art is represented by a single type, known as lead-acid (actually lead and lead dioxide). The advanced battery types now getting the most attention are sodium-sulfur, sodium–antimony trichloride, lithium–metal sulfide, and zinc-chlorine.

The *lead-acid battery* is rugged and reliable, the chosen technology for nearly a century. But its cost is too high for widespread appeal to the electric utility industry. A completely installed system (including such items as cooling and

Table 1
CAPITAL COSTS FOR UTILITY BATTERIES*
($/kWh)

The target: what utilities can afford	*10-yr life*	*20-yr life*
2 hr	25–50	40–80
5 hr	15–35	25–60
10 hr	10–30	20–50
The expectation: what developers can achieve	*10-yr life*	*10–20 yr life*
Lead-acid	50–80	—
Advanced	—	20–35

*The range for each pair of figures reflects wide variation in possible ratios of peak to off-peak energy cost. For peak energy, the crucial variables are generator capital and fuel costs. For off-peak energy, the main variable is fuel cost for the baseload generators used to charge battery storage.

ac conversion) costs about $400/kW for 3 hours of storage, $525/kW for 5 hours, and $1000/kW for 10 hours—equivalent to $133, $105, and $100/kWh, respectively. Furthermore, by utility standards, the battery itself has a limited life of only 10 years.

Also, the lead-acid battery is characterized by a relatively low energy rating per unit of its own weight. (Lead is cheap at $0.25/lb, but the battery requires about 60 lb for each kWh of storage capacity.) This low energy density means a large plant area, and the weight requires greater foundation support. Both are cost penalties.

Probable capital cost ranges for lead-acid and advanced batteries also appear in Table 1, and it is important to compare them with what utilities can afford, particularly for 20-year batteries. The expected costs for advanced batteries fall well below the break-even targets. Predictably, this is not the case for lead-acid batteries. Only an additional cost credit, above the $50/kW already included in the target figures, would raise those figures to a point where lead-acid batteries could assuredly compete.

The main advantage of a lead-acid battery, therefore, is its availability today for situations where, for example, the alternative need for extensive underground transmission facilities produces substantially higher capital cost credits. It may also be a particularly good candidate if new peaking capacity is curtailed by either fuel shortages or local environmental prohibitions.

The *advanced battery,* in contrast to the lead-acid, seeks to use materials affording higher energy densities. Because less material is needed, its unit cost can be greater—while still minimizing overall battery size.

The four advanced battery types are further distinguished by their operating temperatures or use of flowing electrolytes. Zinc-chlorine batteries are the only type at near-ambient temperature (50°C); the electrolyte is water based. Sodium-sulfur batteries operate between 300°C and 350°C and use a solid electrolyte. Sodium–antimony trichloride batteries are similar but have an operating temperature of about 200°C. Lithium–metal sulfide batteries operate between 400°C and 450°C; the electrolyte is a molten salt. The higher temperature is significant in that it is not only associated with higher specific energy density and power ratings but also with materials problems.

Several research approaches are directed toward lower material costs and, by implication, toward better energy density ratings. But even some of these conflict with one another. For example, gaining deep discharge (perhaps to 80%) and increasing current density often requires higher temperatures or more sophisticated designs with flowing electrolytes, which, in turn, increase cost.

Approaches to lengthen battery life involve conditions for long-term reversibility of chemical reactions and the control of impurities that tend to be introduced by undesired reactions among various materials in the battery.

Which battery looks best?

Advantages and disadvantages of the major candidate systems are not absolute; they are relative to one another (Table 2). Compared with lithium, for example, sodium is a plentiful material. Much work with the sodium-sulfur battery has been done with a solid electrolyte of beta alumina, a ceramic.

Table 2 LOAD-LEVELING BATTERIES: CANDIDATES AND CHARACTERISTICS; DEVELOPERS AND DEMONSTRATION DATES

	Operating Temperature (°C)	Theoretical Cell Energy Density (Wh/lb)	Design Cell Energy Density (Wh/lb)	Design Modular Volumetric Energy Density (Wh/in^3)	Depth of Discharge† (%)	Density—10-hr Rate (mA/cm^2)	Acti Materi Cos ($/k
Lead–acid (Pb/PbO_2)	20–30	110	9	0.75	25	10–15	8.5
Sodium–sulfur (Na/S)	300–350	360	70	2.5	85	75	0.4
Sodium–antimony trichloride ($Na/SbCl_3$)	200	350	50	2.0	80–90	25	2.3
Lithium–metal sulfide ($LiSi/FeS_2$)	400–450	430	85	3.5	80	30	4.2
Zinc–chlorine (Zn/Cl_2)	50	210	25	0.7	100	40–50*	0.7

†Also known as utilization of active materials.
*5-hr rate

Functioning also as a separator and frequently as a container for the liquid sodium electrode, this solid electrolyte makes for a simpler design. However, high-quality, suitably sized solid electrolytes of this type have not yet been fabricated by cost-effective methods. In addition, the sodium-sulfur design awaits demonstration, among other things, of seals and a satisfactorily corrosion-proof container for its sulfur electrode. All in all, the sodium-sulfur battery shows the greatest potential for having the lowest materials cost among the advanced battery types.

The sodium–antimony trichloride battery benefits from a lower operating temperature, in part, by its successful use of simple elastic seals. Another attractive feature is its very high cell operating potential (2.6 volts), highest among the four types of advanced batteries. Thus, high efficiency is attainable despite possibly higher internal losses.

However, the current density (per unit area of electrolyte) is about one-third that of the sodium-sulfur battery. It therefore requires more electrolyte for a given capacity, with a resultant implication of higher cost. Also, the cost and availability of antimony are in question.

The lithium–metal sulfide design derives from earlier work with a lithium-sulfur couple having a very high specific energy value but showing a rapid degradation of capacity with time. Substituting solid lithium alloy for molten lithium, and metal sulfide for the sulfur, reduces the theoretical specific energy density by one-half or two-thirds, to where it is comparable with the sodium-sulfur battery. The lithium–metal sulfide battery, which has the highest operating temperature, suffers from materials cost and the problems associated with that fact, as well as from the cost and questionable availability of lithium. Nevertheless, this battery has demonstrated longer life than the others.

Zinc-chlorine batteries are the most complex because of their flowing electrolyte and their need for external storage of chlorine. This complexity is likely to lead to a cost penalty. However, the system has an edge in time required for development and has already performed well in sizes larger than any other advanced battery has even been built.

The step from R&D to commercialization is neither simple nor straightforward for any of these batteries. Yet, very soon battery manufacturers will need the risk capital to build new production capacity. Meantime, it is worthwhile to advance several systems to where manufacturers can visualize the market and their ability to follow through.

Problems of corrosion, seals, impurities, current distribution, and cost are at the R&D forefront today. (Technical details of EPRI-sponsored research are discussed in an R&D status report on page 36.) The schedule still calls for large-scale testing in the national Battery Energy Storage Test (BEST) Facility, beginning in 1980. Demonstration and commercialization are thus possible by the mid-1980s.

Batteries in the big picture

Although technical issues and tradeoffs are important in themselves, the significance of their resolution is to be found in still larger issues. For energy researchers and technologists,

Operating Potential (V)	Demonstrated Cell Size (kWh)	Demonstrated Cell Life (cycles)	Critical Materials	Major Developers	BEST Facility Test (5–10 MWh unit)	Demonstration Station	Commercial Introduction
1.9	>20	>2000	Lead	Gould Inc.; ESB, Inc.; C & D Batteries; Globe-Union, Inc.; K–W Battery Co.	1979	1981	1981–83
1.8	0.5	400	None	General Electric Co.; Dow Chemical Co.; Ford Motor Co.	1981–82		
2.6	0.02	175	Antimony	ESB, Inc.	1981–82	1983–85	1985–87
1.4	1.0	1000	Lithium	Atomics International Division, Rockwell International Corp.; Argonne National Laboratory	1981		
1.9	1.7	100	Ruthenium (catalyst)	Energy Development Associates	1980		

there is the potential of other means of energy storage and of advanced fuels and conversion processes.

And for energy researchers, together with electric utilities and policy planners, both public and private, the still larger issue is the U.S. fuel future: what it can, should, and must be. Not only what fuels, but when, in what amounts, at what costs, and in what mix for use by the national economy in general and by electric utilities in particular.

Today, electric utilities deliver some 2000 billion kWh of energy annually, and 30% of it (600 billion kWh) is fueled by oil and natural gas. By the year 2000, the annual use of electricity will probably be 3.8 times today's figure, or 7500 billion kWh. However, the contribution from oil (and by then a negligible amount of natural gas) will foreseeably decrease to 400 billion kWh. Given the overall increase in electricity generation, together with the decreased availability of oil to fuel it, there will be an estimated annual 1000 billion kWh of peak power that must be fueled by alternatives to oil.

What will fill this gap? According to EPRI estimates, new coal-derived fuels, hydro, solar energy, and coal (for intermediate cycling units) can pick up nearly 600 billion kWh. But energy storage and load management must provide—or shift—the remaining 400 billion kWh.

Some storage may be developed on the customer's side of the meter—as in water and space heating systems charged by solar collectors and nighttime power. But assuming that about 200 billion kWh annually will come from utility energy storage, the implication is clear: a requirement for the installation of 100,000 MW of energy storage that can discharge, on average, for 2000 hours annually.

To meet demand patterns and at the same time make best use of available off-peak baseload generation, a mix of peaking and intermediate storage systems will be needed. Batteries appear best suited for daily peaking, while mechanical and thermal processes under development (compressed air, underground pumped hydro, and heated-media systems) are more likely for weekly cycling.

Batteries versus fuel costs

Despite the critical need for 100,000 MW of utility energy storage by the turn of the century, all such systems must compete in economy with various forms of generation if that degree of penetration is to be realized. And, although storage will ease the transition from oil and gas fuels to coal and uranium, it is difficult—however intriguing—to put a value on this feature. Dollar costs remain a controlling factor for a regulated industry, and electric utilities are thus always motivated to use the cheapest fuel available in the marketplace.

But the marketplace seems far from free as we move toward the future. Availability of fuel is less a matter of reserves and their natural economic development than it is of regulatory policy, international trade balance, and national security. Resolving these issues is the ultimate goal of technical R&D on advanced fuels and conversion processes. The pace of that effort will ultimately be a strong influence on the actual or economic need for battery energy storage.

Sensing the Energy Future

by Milton Searl

Accurate analysis is vital if the U.S. is to meet its energy needs in the year 2000 and beyond. The electric utility industry will play a large role—perhaps the dominant one—in providing that energy. EPRI's efforts in energy supply analysis can have a major impact on the industry's contribution.

□ An EPRI program article

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In a world where energy means progress and where resources are finite while consumption is growing, the future of the nation's energy supply is vital to our economic well-being, national security, and survival.

It is a common projection that energy consumption in the U.S. alone will double by the year 2000. This will require two times as much energy over the next 25 years as Americans have consumed during the last. Will it be there?

The U.S. may have to produce a large part of this energy itself, with greater concern than ever before for environmental effects. Will we be up to it?

In the year 2000 the electric utility industry may be using one-half the nation's total energy supply to produce electric power, and even larger proportions thereafter. Will the industry be ready?

The electric utility industry has a large stake in acquiring more knowledge about our energy supply for the future. Thus, the function of EPRI's Energy Supply Program is to provide the industry with careful, objective, and independent analyses of the future of energy supply. For a research and development organization like EPRI—whose output must ultimately stand the test of commercial feasibility—the need to "sense the future" is essential to its total research program.

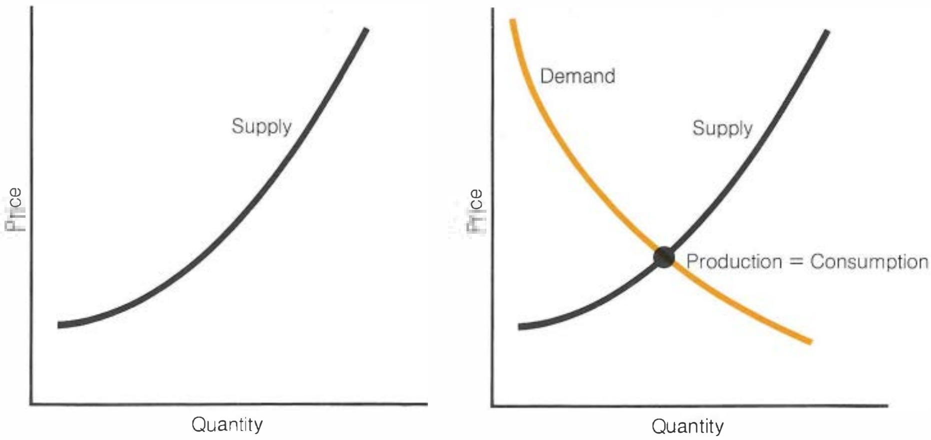


Figure 1 Supply and demand are distinct and separate economic concepts. Their interaction in the market at a specific time determines the level of actual production and consumption.

The concept of supply

Energy *supply* projections through time for various fuel and energy forms are developed in the Energy Supply Program. Energy *demand* projections for fuel and energy forms are developed in the Energy Demand and Conservation Program. To derive estimates of energy production and consumption, these supply and demand elements (as well as other information) are integrated in the Energy Systems Program. (Production and consumption may be taken as being numerically equal for purposes of this discussion [Figure 1], although in short-term analyses, inventory changes may cause production and consumption to differ.)

In its economic sense, *supply* refers to the price-quantity relationship (expressed as a formula, curve, or schedule) in a given time period for a given commodity in a given market. *Production* refers to a specific quantity and its associate price at a given time in a given market. Production represents but a single point on the supply curve.

Historically, with stable energy prices and a predictable growth in consumption, there was little need to separate supply and production projections, particularly for forecast periods of 5–10 years. And, given present lead times for the construction of energy facilities, that may still be the case. For longer time periods, however, questions of resource depletion, supply elasticity, and response to government policy make the future much more uncertain. This uncertainty is best expressed in terms of supply curves (with associate bands of uncertainty). Representing supply separately offers much more flexibility for meaningful use with the now highly uncertain levels of future demand. To a considerable extent this decouples supply analysis from demand. Supply analysis at EPRI is keyed to the information needs of the post-1985 period, since this is when EPRI's R&D efforts are expected to have the greatest commercial impact. Supply projections, since they explicitly incorporate price and other variables, require a deeper understanding of the underlying phenomena than do production projections. Indeed, adequate supply predictions for long-run energy analyses (in contrast to consumption or production predictions) have never been made.

The energy system

Some idea of the organization and structure of the national energy system is given in Figure 2. Although this is one of the better representations, it is neither unique nor complete; the complexity of the energy system is such that it may not be possible to adequately represent resources, functions, technologies, and energy flows in a simple diagram. Even representations of subsystems, such as the coal subsystem, can be quite complex. The chart is, however, adequate for our purposes here.

For our analysis it is useful to consider only energy resources as they exist in nature as the beginning of the energy system and to consider foreign and U.S. energy systems in parallel, introducing imports and exports elsewhere in the energy system.

The shaping of a supply system

In broad perspective, an energy supply system is the mechanism that brings together fixed energy resources and the demands of consumers. It converts natural resources to the quantities and forms required by consumers and delivers them at designated places and times. In a very general sense, it is a conversion system.

Examination of energy supply systems around the world reveals marked differences that reflect the local economic compromises between fixed natural resource endowments and consumer preferences. There is a wide range of

Figure 2 The energy supply system is bounded on one end by primary resources and on the other by end-use conversion. Categorizing the intervening steps is difficult, and it varies with the fuel form and associate technologies. For low-Btu gas, for example, the product transportation step is skipped because transportation economics will require that primary and secondary conversion occur at the same site.

Primary Resources
- Foreign oil
- Domestic oil
- Oil shale
- Tar sand
- Low-sulfur coal
- Natural gas
- Imported gas
- Imported methanol
- Uranium

Resource Extraction Processes
- Import
- Exploration and production
- Mining and extraction
- Mining and retorting
- Surface mining
- Enrichment

Supply Transportation
- Tankers
- Crude pipelines
- Gas pipelines
- Unit trains

Primary Conversion
- Sour-crude refining
- Sweet-crude refining
- Shale refining
- Power generation
- Hydrogen from coal
- High-Btu gasification
- Solvent refining
- Liquefaction
- Methanol refining
- Nuclear-thermal water splitting
- Nuclear power generation

Product Transportation
- Tankers
- Liquid pipelines
- Low-Btu gas pipelines
- High-Btu gas pipelines
- Unit trains
- Power transmission

Secondary Conversion
- Combustion power generation
- Large fuel cells

Distribution
- Trucks
- Tank cars
- Gas lines
- Service stations
- Local deliveries

End-Use Conversion
- Auto engines
- Bus/Truck engines
- Aircraft engines
- Ship engines
- Combustion
- Heat pumps
- Catalytic burners
- Electro-mechanical devices
- Steam generation
- Small fuel cells
- Chemical manufacturing
- General manufacturing

SOURCE: Stanford Research Institute

Table 1 DOMESTIC ENERGY PRODUCTION*

(quadrillion Btu)

	Natural Gas (wet)	*Crude Oil*	*Coal*	*Hydro*	*Nuclear*	*Total*
1945	4.42	9.94	16.53	1.44	0	32.33
1973	25.22	18.75	14.36	2.87	0.85	62.05
Change	20.80	8.81	(−2.17)	1.43	0.85	29.72
% of total change	70.0	29.6	(−7.3)	4.8	2.9	100.0
Ratio 1973/1945	5.70	1.89	0.87	1.99	—	1.92

*Including exports.

accommodation between the forces of demand and resource endowments. In some countries, such as the U.S., the characteristics of the energy supply system reflect a historical dominance by demand factors. In other countries, such as Norway, the nature of available energy resources has played a more important role in shaping the supply system. Energy imports provide still another supply dimension for those countries with limited resource endowments. If economic and political factors are not constraining, they enable a nation to draw on a wider resource base than its own endowment to meet consumer preferences.

In the U.S., as mentioned earlier, the supply system has been dominated by consumer preferences. Consumers have been able to pay for and get energy in virtually whatever form they desired with relatively little difficulty. This situation is sometimes referred to as consumer sovereignty. It has been possible in the U.S. only because this land has been blessed with ample fuel resources: wood, coal, crude oil, and natural gas, each of which has taken its turn as the dominant factor in the growth of the energy economy. (The nation's uranium resources may also be abundant, but this abundance is still controversial.)

The consumer's influence

It is appropriate to consider briefly the characteristics of consumer demand that have shaped the supply system in the past, not only because they help explain the present supply system but also because they will exert a powerful force on its development in the future. The consumer is more concerned with the function performed—heating, cooling, lighting, mechanical work—than with the energy form per se. The consumer prefers to have these functions performed with as little effort as possible—preferably automatically, as with thermostat-controlled heating and cooling, or by a flick of a switch, or at most, with the inconvenience of pulling into a filling station. Although this preference is most evident at the individual level, it is strong at the commercial and industrial levels as well. Certainly a reason (although not the primary one) that many utilities are interested in nuclear power is the freedom it gives from the problems of handling and storing coal.

The supply of electricity and natural gas is so automatic that most residential customers do not fully understand what they are buying. Few householders realize that in using electricity they are also buying availability, reliability of supply, and uniformity of product (e.g., frequency control for clocks and motors), as well as energy and convenience. The demand for these historically little-noticed product characteristics has shaped the electric utility industry. And if major changes occur in the consumer demand for these features, they will significantly reshape the industry over the long term.

Consumer preferences for clean, convenient energy supply, coupled with relatively low energy costs in the postwar period, set the pattern for the U.S. energy industry as it exists today. A major trend from the late 1940s through the 1960s was the shift to cheap, clean, convenient natural gas. Two-thirds of the increase in domestic energy *production* between 1945 and 1973 was in the form of natural gas and associated liquids (Table 1).

To avoid confusion and as a means for comparison, the growth in energy *consumption,* with which most of us are more familiar, is shown in Table 2. While natural gas supplied 70% of the increase in domestic energy production in the 1945–1973 period, it accounted for only 43% of the increase in consumption due to the large increase in oil imports.

Table 2 also indicates the rapid growth of fuel input to the electric power sector. This input would have been much larger if it had not been for substantial increases in generating efficiency during the period.

The shape of the future

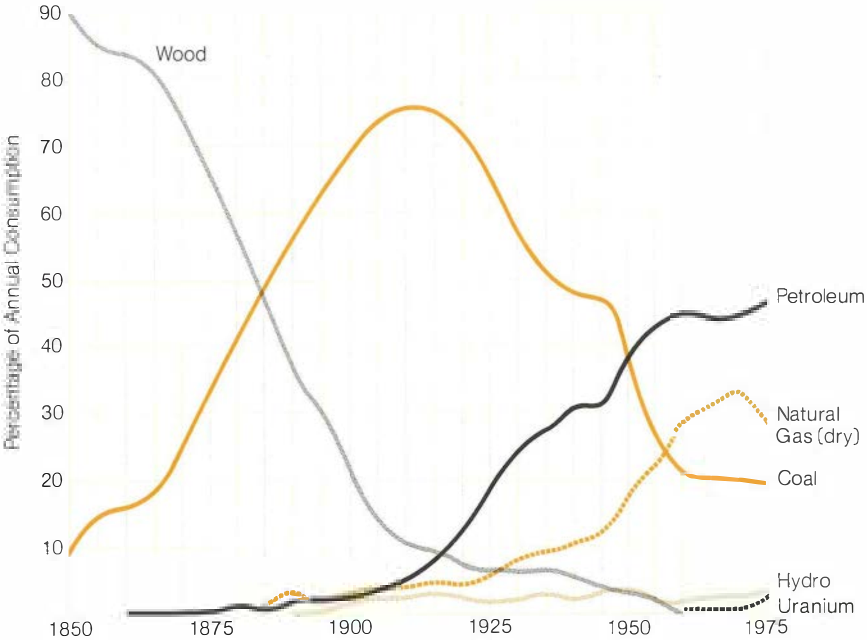
The energy system has been described as a process anchored at one end by a fixed resource endowment and at the other end by an energy-consuming economy reluctant to change its consumption patterns. In those terms, the present strains on the system are due to the attempt to shift rapidly from dependence on one energy base—oil and natural gas—to another—coal and uranium. Historically, the period of change from the predominance of one energy source to that of another has been in the order

Table 2 DOMESTIC ENERGY CONSUMPTION*
(quadrillion Btu)

	Natural Gas	*Petroleum*	*Coal*	*Hydro*	*Nuclear*	*Total*	*Used as Electricity*
1945	3.97	10.11	15.97	1.49	0	31.54	5.48
1973	22.71	34.85	13.29	3.00	0.89	74.74	19.80
Change	18.74	24.74	(−2.68)	1.51	0.89	43.20	14.32
% of total change	43.4	57.3	(−6.2)	3.5	2.0	100.0	33.2
Ratio 1973/1945	5.72	3.45	0.83	2.0	—	2.37	3.62

*Including imports.

Figure 3 Percentage roles in U.S. energy consumption accentuate the successive dominance of major U.S. fuel resources. Because of national growth, actual consumption may continue to rise, even for fuels with flat or falling curves.



of 40 years (Figure 3). To achieve the switch from oil and natural gas to coal and uranium in one or two decades (as has been suggested in Project Independence) will certainly place massive strains on the system. Coal, a proposed mainstay of the revised energy system, was largely rejected by consumers in the past because it lacked cleanliness and convenience. In addition, its increased use entails the prospect of further environmental pollution and raises a number of health and safety questions. Nuclear power, coal's proposed partner in the transition, is a technology about which some observers have serious reservations.

Projections of the long-term energy future abound but lack substance. The Ford Foundation's Energy Policy Project (EPP) presents three growth scenarios (in quadrillion Btu) that illustrate the range of thinking.

	1973 (actual)	*1985*	*2000*
Zero energy growth	74.7	88.1	100.0
Technical fix	74.7	91.3	124.0
Historical growth (1950–1972)	74.7	116.1	186.7

Although these estimates convey the range of potential energy requirements, they do not convey either the uncertainty faced by energy suppliers or the problems of changing from an oil and natural gas energy base to a coal and nuclear energy base, while expanding output at the same time. To illustrate the difficulty of the shift: If the 1973 total energy consumption doubled (i.e., to 150 quadrillion Btu in the year 2000) and all energy were supplied by coal and nuclear power, the required growth rate of the two combined would be a phenomenal 9.1% per year.

The electric power industry is in the vanguard of the forces seeking to reshape the supply system to draw on a more abundant resource base and a new resource and technology (nuclear) with minimum disturbance of consumer preferences. Only the electric power industry has the industrial base to possibly effect the transition. For other theoretically acceptable energy forms—high-Btu gas from coal or hydrogen from coal and nuclear energy—neither an acceptable technology nor an adequate industrial base exists to support a massive transition by the end of the century. Nevertheless, with adequate support and with research and development success, these two forms could make significant contributions.

Estimating resources

The focus of energy supply research at EPRI is on the post-1985 era, although some consideration must also be given to the intervening period, which is along the pathway to the future.

In terms of substance, supply analyses fall naturally into two categories: one dealing with the occurrence of natural resources and the other with the conversion of natural resources into fuel and energy delivered to the consumer.

There are many misconceptions about our energy resources. The most fundamental misconception is that a great deal of scientific data have been gathered on the size of our resource endowment and that someone (e.g., government or the oil companies) has a good estimate of our energy resources. Unfortunately, this is not the case. Considerable geologic investigation has been done on specific basins, formations, or fields, all of which contribute to the overall estimate of the resource endowment. But this does not really delineate its ultimate size. Furthermore, much of the work on the nation's total resource endowment has been done by individuals more as an avocation than as a vocation. Only recently the U.S. Geological Survey made an extensive reappraisal of domestic crude oil and natural gas resources. But even that effort did not deal in a systematic way with the resources that may become available at the higher oil and gas prices now prevailing.

Another popular misconception is that a nation finds its best resources first, and as it depletes its resources, prices rise. Experience with domestic oil discovery belies this simple model. Although oil was discovered in the U.S. in 1859, it was not until 1930 that the nation's second largest oil field was discovered (East Texas) and not until 1969 that its largest field was discovered (Prudhoe Bay).

Moreover, the trend of crude oil prices before the Arab oil embargo prompts questions about the impact of resource depletion. The long-term trend of crude oil prices in the U.S., measured in constant dollars, has been slightly downward, not upward. Evidently, therefore, the effects of depletion have been more than offset by advances in technology.

Research on energy resource endowment has several facets. One is to carefully examine past and current resource estimates of others in order to better understand the bases on which those estimates were made. It has become quite clear that many uranium, crude oil, and natural gas discoveries have not been counted in reserve or resource estimates because they were noncommercial at the time. The analytic challenge is to develop estimates of the amount of resources that have been discovered but not counted, in order to understand our resource endowment.

Existing energy resource statistics can be quite misleading, even if they are accompanied by cost figures. ERDA and its predecessor, the AEC, have long published uranium reserve and resource estimates by $8, $10, $15, and $30 "cost" categories (specifically defined as forward-cost categories by those agencies). Many economists and geologists, including the AEC itself, have used those figures to derive uranium price schedules. Yet information released by ERDA a year or two ago indicates that 89% of the uranium in the above-$10 category occurs in the same deposits as uranium in the $10 and lower categories (i.e., it is associate, or halo, material). Contrary to past interpretations, the figures provide essentially no information on whether or not there are large amounts of uranium in separate lower-grade deposits recoverable at $15 or $30, thereby invalidating the multitude of past analyses that used the AEC cost categories as parts of their uranium price schedules. One of the major objectives of EPRI's work is to clarify the meaning of ERDA's uranium reserve and resource data.

Basically, for all energy resources, EPRI's program seeks to develop estimates of the resource endowment in physical terms independent of economic factors (i.e., in terms of geographic and geologic information, deposit size, depth, grade, frequency of occurrence, and similar factors). All past resource estimates, except a few volumetric estimates, have hopelessly confused economic and physical factors. Resource estimates abound with undefined qualifiers (such as "discoverable," "recoverable," and "reasonable prices") that vitiate their validity for long-term supply analysis.

Although there is no doubt that EPRI's Energy Supply Program can contribute to the improvement of resource estimates and to a greater understanding of the estimates of others, perhaps the most important contribution the program can make will be to the methodology of resource estimation. Some progress has already been made in this.

Supply analysis

The second major component of the Energy Supply Program's contract studies involves research directed at the response of the supply system to price and other stimuli—that is, under what terms and conditions domestic (and foreign) resources will be discovered, developed, produced, converted to the forms in which consumers demand their energy, and delivered. Figure 2 shows that three basic types of activities take place between resource estimates and end use: discovery and extraction, conversion (e.g., electricity production), and transportation (or transmission).

The discovery, extraction, and conversion processes can be further separated into two categories: those that are more or less established commercially and those that depend on a new resource or a new technology (e.g., solar). EPRI's Energy Supply Program treats these categories in a separate but coordinated manner. For each category a somewhat different analytic approach is appropriate. Where production and conversion are both accomplished by established techniques, there exist historical data that are more or less amenable to conventional economic and statistical analysis. But even in these areas the events of recent years have produced discontinuities that require that standard analytic tools be supplemented with professional judgment. Although the analysis of supply from conventional resources and technologies will be along traditional lines, it will differ by emphasizing more specific technology evolution factors, uncertainty factors, and cost and price expectations rather than just cost and resource depletion effects.

In the case of new technologies for energy production and conversion (e.g., in situ coal mining and geothermal power), there are few data and very little experience on which to base analyses. Research in these areas is therefore much more dependent on engineering process analyses and on engineering-economic analyses, together with informed judgment, than is the research on established technologies.

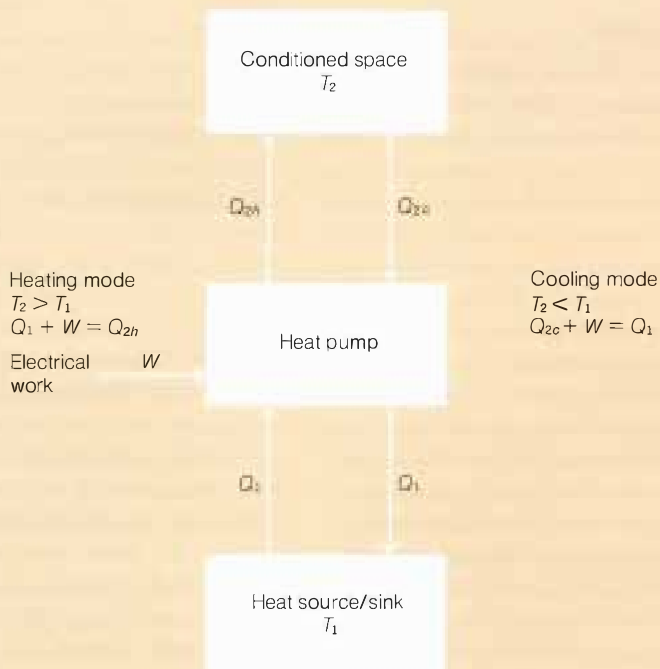
Energy delivery, which includes transmission, transportation, and distribution, is a rather neglected aspect of supply analysis. In the past, there was not much to interest the analyst in these areas, so analyses tended to be superficial. Today, however, with the need to ship low-sulfur coal to distant power plants and with technological developments such as coal slurry pipelines and cryogenic transmission systems, any comprehensive supply analysis should include a new examination of the cost and capability of the transportation system. Such analyses are being undertaken in the Energy Supply Program, as is a modest effort to analyze potential shortages of labor, water, capital, and equipment that might limit energy expansion.

As part of its research strategy, the program staff is also seeking to improve the data and methodology used in supply analysis. More sophisticated application of existing techniques can carry analysis only so far. Research directed at improving data and methodology is an investment in better tools for the future.

The Heat Pump: Renewing an Option

by Robert Crow and Joseph Pepper

Figure 1 The heat pump is for all seasons. In winter, electricity is used to drive a compressor to extract energy, Q_1, from a source (usually outside air) and then deliver energy, Q_{2h}, to the conditioned space. In the summer, the same device is used to remove energy, Q_{2c}, from the conditioned space and reject energy, Q_1, to a sink. In this mode it functions as an air conditioner.



Greater reliability could spur adoption of the electric heat pump for home heating and cooling. Current research therefore focuses on improving the heat pump's reliability, as well as performance, and on assessing its impact on residential loads. ▫ An EPRI technical article

The heat pump may be considered an emerging technology, even though the fundamental physical and engineering principles are well known and the equipment has been on the market for some time. But because a bad reputation has dogged the heat pump, its use has been limited in recent years. During the late 1950s and early 1960s, a combination of poor design, insufficient testing, and inadequate service triggered reliability problems for homeowners and electric utilities alike. Only now is a conservation-minded nation giving the electric heat pump a long second look.

EPRI's research on heat pumps has a dual focus. The first is the development of improved technology. The second is the assessment of its load and use characteristics and of socioeconomic factors

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related to the possible widespread adoption of heat pumps. Is there, for example, really a substantially larger market for an improved heat pump? And if so, how will the expanded use of heat pumps affect electric utility loads?

How it works

For purposes of this discussion, we will limit our remarks to the electrically driven, vapor-compression heat pump (Figure 1). Heat pump performance is measured by a coefficient of performance (COP).

$$COP_{heating} = \frac{\text{energy delivered}}{\text{compressor work}} = \frac{Q_{2h}}{W}$$

$$COP_{cooling} = \frac{\text{energy removed}}{\text{compressor work}} = \frac{Q_{2c}}{W}$$

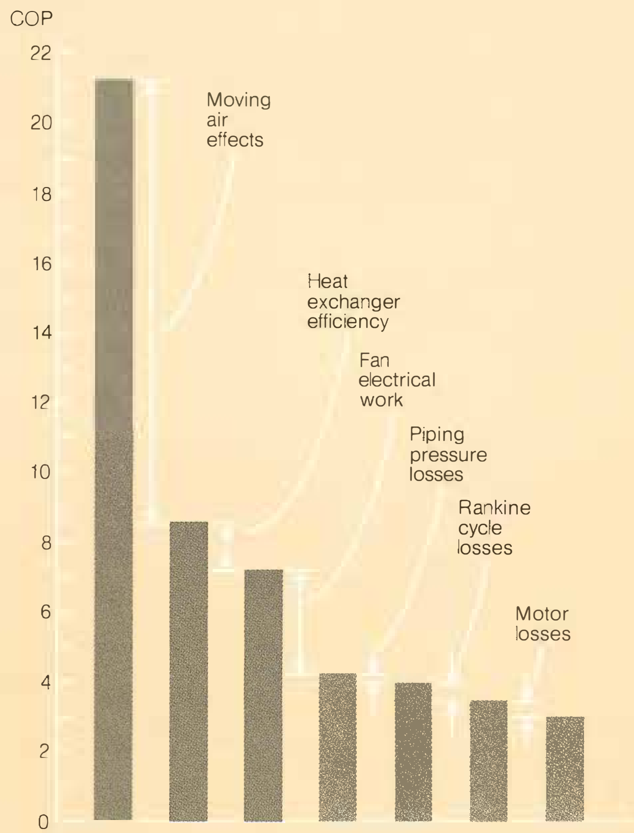
Since Q_1 is a function of T_1 (heat source or sink temperature) and Q_2 is a function of T_2 (conditioned space temperature)—and these temperatures are different, depending on the time of year—these two COPs are not equal. On an annual basis, the seasonal performance factor reflects the weighted average of the cooling and heating COPs.

For an ideal heat pump, the COP can be expressed in absolute temperature units (°R) as $T_1/(T_1 - T_2)$. Thus, for 45°F ambient (505°R) and 70°F indoors (530°R), the COP would be 21.2. Figure 2 shows how, due to a variety of "real world" effects within the mechanism itself, the COP is reduced to 3.0 or less. It is even lower in a poorly designed, poorly insulated structure.

However, even at this less-than-ideal level of performance, the heat pump adds 3.0 units of energy to the air circulation system for every unit of electric energy consumed by the compressor. In contrast, electric resistance heat has essentially a COP of 1.0. Thus, in this example, the heat pump uses only 33% of the electricity that a resistance system requires to meet the same heating load.

For economic reasons, the heat pump is usually sized to meet its anticipated cooling load. And because the heating

Figure 2 Six practical considerations drastically reduce the coefficient of performance (COP) of a heat pump from its theoretical maximum—in this case 21.2 for 45°F ambient and 70°F indoors. Moving the ambient air over the outdoor coil reduces it to 35°F, and it must be heated to 100°F for distribution indoors. The theoretical COP for this wider actual temperature difference is only 8.6. A perfect heat exchanger requires infinite heat transfer area; a practical one requires a still greater temperature differential, thus reducing the COP to 7.1. Electrically driven fans to move the air are a practical requirement: thus, 4.2. Pressure drops in valves and piping are unavoidable: 4.0. Heat pump operation actually follows the Rankine cycle, which is not as efficient as the ideal (Carnot) cycle between the same two temperatures: 3.5. Finally, motor losses are accounted for: 3.0.



SOURCE: W. A. Spofford. "Heat Pump Performance for Package Air Source Units." *ASHRAE Journal*, April 1959.

load is larger than the cooling load in many parts of the country, supplemental heat, usually in the form of resistance strip heaters, must be added to meet the heating demand when ambient temperature drops below a certain level.

This use of supplemental heat has two effects. First, the homeowner's electricity savings shrink because a portion of the heating must be done with a device having a COP of 1.0 rather than 3.0. This lower COP means a greater use of electricity to meet the same annual heating need. Second, from an electric utility's point of view, a significant problem arises when several cold days require most of the demand to be met by the strip heaters. Thus, the utility may see the heat pump as reducing annual electricity sales, yet requiring the same generating capacity as resistance heating—which, in turn, leads directly to lower annual load factors. Part of this loss may be offset by new heat pump customers who previously used oil or gas heating.

Until recently, these drawbacks for both consumers and utilities limited interest in heat pumps and there was little incentive to improve heat pump technology. But technological research is now under way.

Updating technology

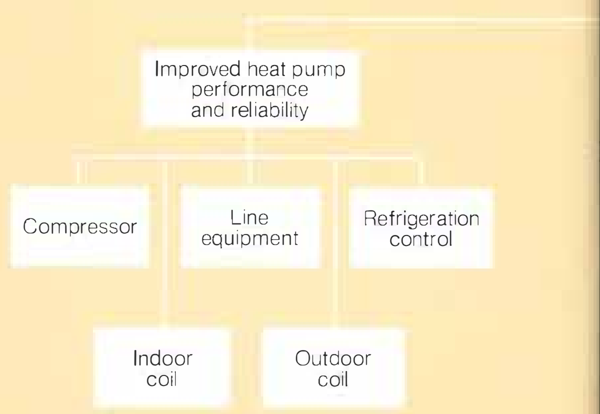
The major objective of EPRI's heat pump technology program is to accelerate the development and acceptance of improved heat pumps. Upgrading other heating, ventilating, and air conditioning (HVAC) components can affect performance of the heat pump itself (Figure 3). Therefore, research also addresses the entire HVAC system and its interaction with the electric utility. As we review the other subsystems, an important point should be kept in mind: For any given climate and usage pattern, the first step in conserving energy is to measure the potential savings to be realized from designing energy-efficient new structures or from "buttoning up" existing ones.

In the compressor, such potential improvements as heat leak suppression, secondary loss reduction, capacity modulation, and volumetric efficiency increase need to be investigated, analytically and experimentally. Both the indoor and the outdoor coil performance may be improved by increasing the amount or the effectiveness of the coil surface area or by increasing the airflow over these surfaces. Modifications to accumulators (line equipment) to improve oil-refrigerant separation or to handle mixed refrigerants need to be studied, particularly in regard to their effect on reliability. Various refrigerant control devices, such as a subcooling control valve on the refrigerant leaving the indoor coil, would appear to offer capacity modulation benefits.

The potential effects of proper load management on heat pump technology are twofold. Proper control of how and when the heat pump operates will not only enable the heat pump to operate less under off-design conditions (a major cause of failure) but will also require less technology improvement to effect the same performance and reliability gains.

Several techniques exist or have been proposed for improving system performance by limiting the conditions under which the heat pump is called on to operate. The reliability of the unit is a direct function of the on/off cycles under extreme ambient conditions. The most

Figure 3 Facing the facts of climate and building use—including building design and modification—is the first step in improving an HVAC system. Thereafter, heat pump developers must identify and organize the factors that influence system capital and operating costs in order to choose the most cost-effective avenues for improving the heat pump itself.



publicized of these methods would use solar collectors to maintain a thermal store at some "charged" condition. That way the source temperature of the heat pump would have a controllable lower limit. Other methods include using groundwater or waste heat (in industry) as heat sources.

Cold weather and solar heat

EPRI has two major projects under way in the area of heat pump technology development. The first is an investigation of methods to improve heat pump performance and reliability in a northern climate and is being carried out at the Westinghouse R&D Center in Pittsburgh. One objective is to measure the benefits expected from a variety of heat pump improvements as well as those attributable to solar augmentation or to thermal storage. Another objective is to assess the impact of a widespread adoption of several preferred systems on utilities and on manufacturers.

The second project, individual residential load center solar heating and cooling, is with Arthur D. Little, Inc. The objective is to develop effective residential system designs to carry out the functions of hot water heating only; both hot water and space heating; or hot water and space heating, plus space cooling. The technology options under study are conventional, load management, solar only, and solar and load management.

The next phase of this project will involve the detailed design of 10 experimental homes, with construction to begin in early 1977.

What is a preferred system?

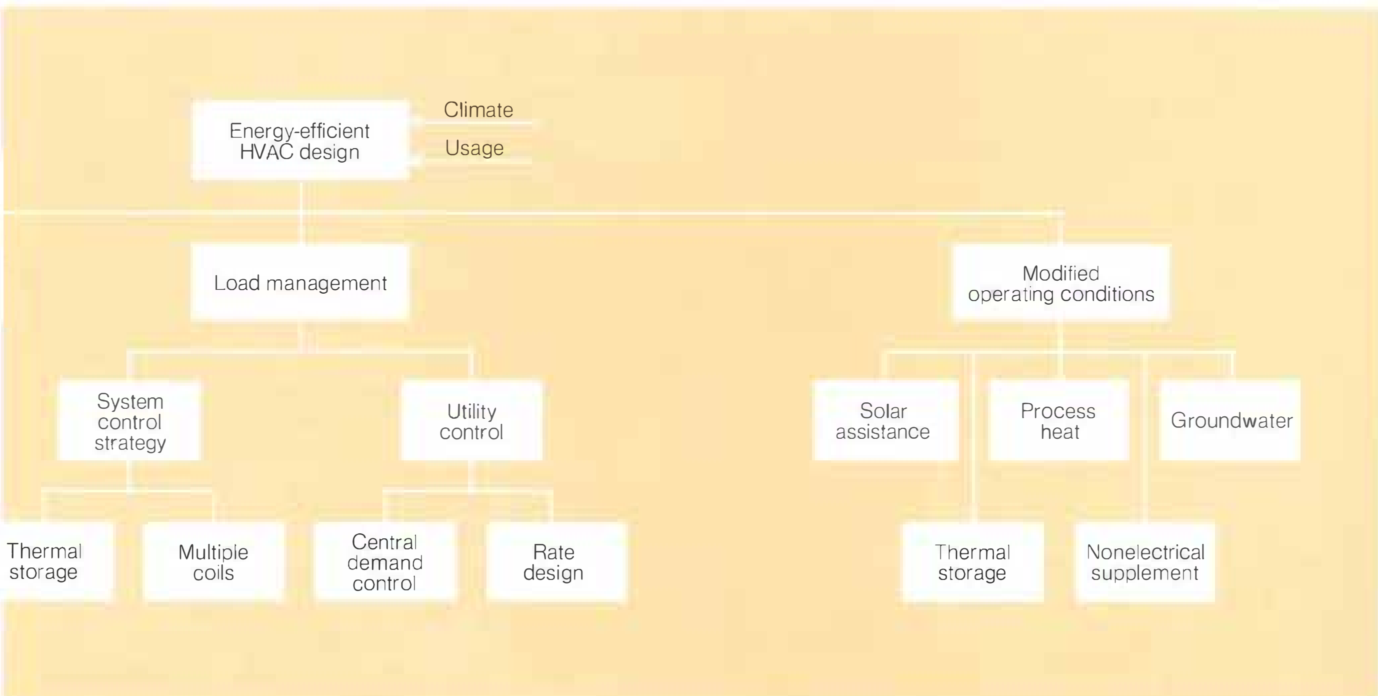
Currently, HVAC systems are selected on a first-cost basis—that is, on the cost of the equipment and its installation. A "preferred" system would be one that takes into account the utility's cost to generate the electricity (capital, fuel, and operating and maintenance) and the user's costs to buy *and* operate the system. Also, characteristics affecting comfort (such as draftiness and noise) and other relevant aspects of performance (such as reliability) would be considered.

Starting with a basic, currently available heat pump, each of the potential improvements can be investigated incrementally as to its effect on performance and cost. Each of the methods should, of course, be investigated for cooling as well as heating. It is also crucial to recall that lack of reliability, rather than poor performance, has been the downfall of the heat pump in the past. For this reason, the reliability impact of any change will be paramount in the selection of a preferred system.

Assessing load impact

Research to assess the potential impact of heat pumps on utility systems is spurred by the fact that heat pumps are already being installed in growing numbers. Increased knowledge of how heat pumps perform and how they are actually used is thus of immediate value.

The ramifications are by no means straightforward; they will differ among utility systems. For example, a summer-peaking utility might regard heat pumps as an unmitigated blessing because they can help build heating load and foster greater sales without a corresponding increase in capacity. But a winter-peaking utility might find that heat pumps add more to a heating peak than to baseload if they require resistance heating backup



systems on very cold days.

To assess the load impact of any emerging technology, we need: (1) data on the technology's performance and on consumer usage and behavior patterns; (2) assessment, through quantitative modeling or other means, of the degree to which the technology will be accepted by potential consumers; (3) assessment of the prospects of a supply industry developing to meet the market potential; (4) forecasting models of the annual, seasonal, and time-of-day usage patterns of the new system; and (5) translation of information from the above four steps to estimates of the impact on typical utility system loads representing a range of climatic and economic conditions.

Monitoring home use

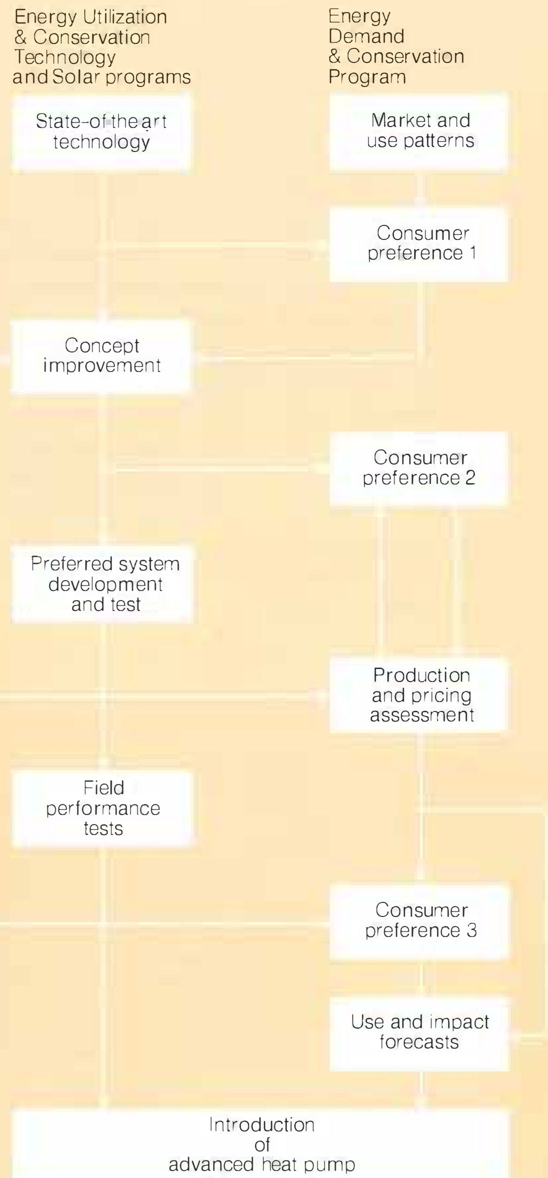
Of current projects relating to impacts on utilities, the principal one is sponsored jointly with the Association of Edison Illuminating Companies (AEIC). The project is an attempt to find out as much as possible about the performance and load characteristics of recent-vintage heat pumps in actual household use.

Twelve participating utilities across the nation provide a broad sample. About 10 houses in each utility service area—representing a wide variety of heating requirements, as measured by degree days—are being monitored during the course of the study. The houses are typical single-family residential units located near special weather stations provided by EPRI for each group of houses. Data are being collected for approximately one year, with some possible exceptions to capture a second heating season.

The project is designed to be consistent in every way possible with a project on fuel utilization in residential heating and cooling that is developing a simulation model of the performance of major HVAC systems, based on field test data. (For a more complete description of this project, see the July/August issue of the EPRI JOURNAL, pp. 43–44.)

On the completion of these two studies the data developed and the simulation program will be used to analyze heating

Figure 4 Improving the residential heat pump involves interaction between EPRI's research programs in technology and economics. Step-by-step progress of several projects in three programs will lead from today's state of the art to the introduction of an advanced heat pump.



and cooling loads. In a second phase, these findings will be translated to an analysis of the impact of the heat pumps on electric utility system loads under alternative scenarios of heat pump saturation, climate, and other relevant variables.

Simultaneously, a model will be constructed to forecast heating and cooling system saturation as it relates to variables affecting builders and household customers. This study will include not only the heat pump but also all other forms of electric, solar, and direct fossil heating. These last two studies—the development of a technique to determine the impact of a given number of heat pumps on utility system loads and the forecasts of heat pump saturation—will be used to perform actual conditional forecasts on the impact of air-to-air heat pumps on electric utility system loads.

Future projects will also investigate the market potential and utility system impact of water-to-air heat pumps, heat pumps in commercial applications, and heat pumps in industrial heat recovery systems.

Meshing disciplines

At EPRI, assessing the market potential of end-use technologies and their impacts on utility system loads is part of the Energy Demand and Conservation Program. Research on heat pump technology itself is performed within the Energy Utilization and Conservation Technology Program and the Solar Energy Program.

A general scheme of the interrelationships between programs may be seen in Figure 4, which shows the flow of information within and between the various programs. The figure also gives an overview of the way in which socioeconomic studies can be coordinated with technological work to bring new systems into practical operation.

The first input in developing research on an energy-using technology is a thorough knowledge of the state of the art in that technology and in competing technologies. In the case of heat pumps, we need to know the performance characteristics, fixed costs, and energy costs of heat pumps and competitive HVAC systems.

At the same time, we need to know the socioeconomic factors relevant to the market for which the technology is being produced. What do potential users of an improved residential heat pump system really want? This question triggers the first round of analyzing product acceptance and use patterns.

Combining what we know about the technology with what we can learn about consumer preferences yields a clearer idea of our target. This concept improvement and analysis step gives us a working concept of the new system—how it is expected to perform and what it will probably require in the way of capital and operating costs.

Concept improvement and analysis leads to the identification of preferred systems, prototype development of such systems, and bench testing or other experimentation with the prototype. To the extent that such a preferred system appears promising, the technology development programs provide data for a preliminary assessment of potential production by equipment manufacturers and some estimate of the price at which the equipment may be sold. However, estimates of potential production and price also depend critically on information concerning consumer preference. Hence, there is a two-way relationship between market research and an assessment of potential production.

If, as a result of attempts at prototype development and experimentation, the preferred system is found to be infeasible, it is not necessary to work further on concept improvement and analysis. But if the preferred system still appears promising, field testing begins to develop information on its energy efficiency, reliability, installed cost and operation cost, and other characteristics relating to system performance. In the case of an HVAC system, those other characteristics might relate to comfort—for example, to the rate of airflow, the rate of response to differences between room temperature and thermostat setting, or the amount of fan and compressor noise. Information on field test results plus information on product prices then leads to a third round of investigations of market acceptance and usage patterns.

Finally, armed with estimates of the potential supply of new-system units, unit prices, and product acceptance and usage patterns, we can develop forecasts of the number of units in use and their time-of-day and seasonal utilization patterns. This information, in turn, indicates their probable impact on utility system loads.

Closing the research circuit

Forecasts of the units in use and the results of field testing shape manufacturers' decisions as to whether the product under investigation—in this case, the advanced heat pump—is a commercially feasible venture. If field testing has revealed hidden problems, the product is rejected, and we must go all the way back to concept improvement and analysis in order to focus on whatever failures of component or system design have emerged. If the new system passes muster in the field and is judged to be feasible, it becomes part of the state of the art, and work begins anew to design an even better system. Thus another cycle is launched in the continuing research process.

EPRI's research on heat pumps, then, follows two separate but interrelated paths. First, the heat pump itself must be improved. Second, such improvement must be scaled to the needs of potential users, and the probable impact of increased use on electric utility loads must be carefully assessed.

Technological innovation and economic research are joining forces to revive the heat pump as a viable option for home heating and cooling. This option holds considerable promise as an alternative to electric resistance heating and to direct heating by fossil fuels. And its possibilities are not only residential. If advanced heat pumps perform reliably in houses, then they may be scaled up for use in existing commercial applications.

Tom Kimball: Deciding for the Environment

Thomas L. Kimball of the National Wildlife Federation and a member of EPRI's Advisory Council takes a sharp look at energy use and the quality of life. ▫ An EPRI interview

Tom Kimball, a mild-mannered Arizonan and dedicated environmentalist, likes to point out that the National Wildlife Federation has enjoyed a membership growth of 8% a year for the past 15 years. As executive vice president of the 3.5-million-member federation, Kimball sees this expansion and that of other environmentalist groups as "evidence that Americans are deciding there is more to the quality of life than cheap energy and materials and membership in a throwaway society."

But he is alarmed over the projected growth of energy demand in the United States, and he disagrees that the historical growth rate of 6% a year for electric energy demand is inevitable. Kimball's membership in EPRI's Advisory Council enables him to present the conservationist position to the utility industry.

"There is a direct relationship," Kimball points out, "between our economic growth, the things we produce for the good life, and energy consumption. And as long as we have additional numbers of people who expect those good things, there's going to be growth in energy demand that has to be met. So I've suggested that when you do research and study the various options of fuels and technology, you crank into that research a concept of not forgetting to take a look at the impacts on the environment."

This concept of environmental balance in research brings up the issue of energy conservation. "We have used more energy than we needed to run our society," Kimball says, citing recent studies by the U.S. Office of Emergency Preparedness and the Energy Policy Project (1974) of the Ford Foundation.

"This excess—25% more energy than we needed—did not improve our standard of living," Kimball observes. "In fact, it reduced the quality of our life by pouring more pollutants into the air and water and damaging our landscape."

Kimball sees the 25% energy excess as waste. "It is energy for which, in many cases, a demand was artificially created by advertisements and inducements based on the concept that the more you

"We have used more energy than we needed to run our society."

use the cheaper it gets," he says. "Our industry became obsessed with the built-in obsolescence syndrome and the throwaway mentality." Moreover, he adds, that energy excess "has exacted a very real economic toll on the consumer."

Kimball gives examples of what he sees as waste. "I don't consider it essential or desirable to produce energy-intensive aluminum beverage cans that are used once and thrown away, only to contribute to a horrendous solid waste and litter problem," he tells us. "Nor do I consider essential or desirable the use of over one-half billion gallons of gasoline a year getting to and from football games when mass transit and viewing the games on television are alternatives. And how long can the American housewife justify using more energy in her self-cleaning oven than the entire yearly per-capita energy consumption of the poorer half of the world's people?"

Referring again to the Ford Foundation Energy Policy Project, Kimball notes that the study found that an annual energy growth rate of just 2% is not only possible, but "desirable, technically feasible, and economical." Kimball looks to conservation and cutting waste as the key to scaling down to that rate of growth. At the same time, he recognizes that all the methods for doing so are not yet at hand and that a federal conservation policy is still lacking. He points to ways of achieving an overall reduction of 25% in energy consumption and making savings in energy resources of between 40 and 75 quadrillion Btu by 1990.

In transportation, which uses about 25% of our total energy supply, Kimball says we now rely on the least efficient modes—automobiles, trucks, aircraft—rather than the most efficient—bus, railway, and waterborne transport.

"If we shift one-half of the freight and one-third of the passenger traffic to more efficient modes, we could save 20% of the transportation energy budget, or 5% of the total energy budget," he says.

One-quarter of the energy used in the United States is consumed by industry, which could conserve from 6% to 10% of that by 1990, even without recycling, Kimball adds. He cites a report by the U.S. Office of Emergency Planning that claims higher energy savings are within reach. "From discussions with industry engineers and trade association staff members," the report says, "it appears that, with the possible exception of the primary metals sector, the steel, aluminum, chemical, and petroleum industries could easily cut energy demand by 10% to 15% (and probably much more) . . . by accelerated retirement of old equipment, more energy-conscious process design, and upgrading and increased maintenance of existing equipment."

"I deplore the burning of hydrocarbons for production of electrical energy."

Residential and commercial buildings use one-fifth of our total energy—and nearly 90% of that is for space conditioning, Kimball notes. The use of FHA minimum insulation could cut heating and cooling energy needs by 25% to 40%, he asserts. Reduced lighting intensity and use of fluorescent lamps would effect further savings. Altogether, Kimball says, the residential and commercial conservation potential is 35%, or more than 7% of total national energy use.

The electric utility industry is a special case, since its use of energy is largely accounted for by the residential, commercial, and industrial sectors it serves. But Kimball feels that utilities could achieve savings themselves by more efficient heat use and could encourage savings elsewhere by load leveling through restructured rates. He believes that electric utility rates should increase (not decrease) when a customer's consumption rises. In other words, electricity should get cheaper as you use less, contrary to current industry practice.

But most important to Kimball is the efficient use of heat sources. "I deplore the burning of hydrocarbons for production of electrical energy," he says. "When future generations look back on our decisions, we'll be seen as a very wasteful generation because coal, oil, and gas can be used for so many other purposes. You can make food; you can make cloth; you can make pharmaceuticals out of hydrocarbons. And to burn them under a boiler seems very wasteful to me." Kimball would like to see more R&D money plowed into development of alternative sources of energy. And he welcomes EPRI's substantial involvement in this direction.

Kimball keeps an eagle eye on the effects that meeting our national energy goals have on the environment. "The marketplace should determine which fuel and energy technology will be forcefully pursued," he says. "But it can do this adequately only if the costs of preventing environmental degradation are fully 'internalized,' that is, if they are taken into account and included in the cost of the product or process.

"The various potential energy sources have different impacts on the environment," he continues, "and judging them by some common criteria gives us an idea of how well each source would fare if the environmental costs were indeed internalized." Kimball lists the major criteria.

"The most obvious one," he says, is that "the best energy source is that which pollutes least in the production of power, taking into consideration such things as thermal discharge, air and water contamination, disposal of residue, and noise.

"Another criterion must apply the same general standards to the extraction of whatever fuel is used in the production of socially useful energy."

Still another measure is "the issue of land use implications, which include the condition in which the land is left following fuel extraction and the associated land use considerations such as growth of cities and processing facilities, as well as the actual use of land by a generating station."

As a final consideration, Kimball cites "esthetic values, which include such things as impact on scenic or historic places."

Pragmatically, Kimball realizes that "minimizing the environmental costs involves recognizing the trade-offs between environmental protection and energy production and choosing methods that give the greatest amount of energy at the least environmental cost."

Kimball adds that "adverse environmental impacts exact real costs in human and economic terms. We believe that by requiring that these environmental costs be taken fully into account, free market factors will ensure that any trade-offs will be minimal in terms of adverse environmental impact. We also believe the marketplace is more effective than simple regulation, because it also encourages socially desirable innovation."

Kimball strongly believes that "public evaluation" of alternative energy sources "is essential, healthy, and long overdue."

He gives an environmentalist's summary evaluation. "Nuclear power rates very high in some environmental criteria and very low in others, such as waste disposal. Solar, geothermal, and nuclear fusion appear to hold greater promise with their virtually unlimited fuel supplies than does the breeder reactor, in the category of availability of fuel. Geothermal power plants have a very low cost per installed kilowatt, but they present some environmental problems that still must be solved. The in situ gasification of coal and the production of shale oil by the same method show great promise and are far along in demonstrating commercial feasibility.

"I expect some significant breakthroughs in the next five years in reducing the cost of photovoltaic cells," he predicts. "And we are just beginning to scratch the surface in recovering energy from wastes and in recycling natural resources we now throw away."

Although "some say that the world cannot wait for the development of these alternatives," Kimball notes, "I and many other conservationists disagree, and studies such as the Ford Energy Policy Project strongly support this position."

He adds, "We believe it is clearly not in the public interest to plunge ahead with massive development of any of the conventional energy sources, with their attendant environmental and other impacts, unless that becomes absolutely necessary."

Kimball stresses that "conservation, efficient use, and the elimination of waste can buy us time to properly evaluate the variety of options and select the proper course of action."

Thomas L. Kimball, as executive vice president of the National Wildlife Federation, directs the world's largest publicly supported conservation group, with more than 3.5 million members and supporters and with affiliates in the 50 states, Guam, the Virgin Islands, and Puerto Rico.

An internationally recognized conservation leader, Kimball served the United States as a member of advisory committees of the Department of the Interior, the Department of Agriculture, the Department of Housing and Urban Development, the Department of Commerce, and the Department of State. He also served a three-year term on the president's Air Quality Advisory Board and has been a consultant to wildlife agencies in six states.

Kimball was a member of the American delegation to the first meeting of the U.S.—USSR Joint Committee on Cooperation in the Field of Environmental Protection, held in Moscow in 1972. And he was a delegate to the International Whaling Commission conference in London in 1974. Kimball serves on the executive committee of the United States National Commission for UNESCO and is a member of its committee on Man and the Biosphere. He also belongs to the International Union for Conservation of Nature and Natural Resources. And he is a charter member of the EPRI Advisory Council, representing the public's environmental interests.

Kimball was director of the Arizona Game and Fish Department from 1947 through 1952 and then directed the Colorado Game and Fish Department from 1952 to 1960, when he joined the National Wildlife Federation. He is a graduate of Brigham Young University in Provo, Utah, and served in the U.S. Army Air Corps during World War II.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty Director

WOOD-RELATED RESEARCH

Don't dump that fly ash. If it is combined with ground glass, melted, extruded, and cured, the result is a utility pole that is stronger and longer-lasting than wood poles. Development of a power pole from fly-ash-derived foamed glass (RP851) has been instituted as a follow-on to a feasibility study (RP482) for such a pole. The overall objective of the follow-on project is to develop the continuous manufacturing techniques required to produce full-size foamed-glass power poles that are competitively priced. There are two efforts: (1) to demonstrate the continuous production of the poles in a pilot plant, and (2) to produce full-size 40-ft power poles and evaluate their operational properties. The feasibility study demonstrated a potential savings of 30–70% of the present cost of both transmission- and distribution-class wood poles, and an even greater savings when compared with concrete or steel poles.

Two additional benefits are obvious. Because the foamed-glass material is inert, pole service life is not shortened by decay. The process uses two waste products, fly ash and waste glass, as the major ingredients for the foamed-glass pole. Replacing the roundwood pole, a prime natural resource, with waste products is a sound conservation measure.

Tensile strengths of 5000–8000 psi can be achieved by varying the density of the foamed glass. These values equal or exceed fiber stress values for the three major wood pole species.

The project will also develop an extruder to form a one-piece, tapered, hollow, square or rectangular cross-section pole. Use of several pole segments to make up longer poles will be explored and evaluated in the interest of lower production facility costs. Process and production facility specifications will be available upon completion of the project. The contractor is ECP Inc.

Another roundwood pole substitute project has recently been initiated with Michigan Technological University (RP796). Specifically, the contractor is to develop a suitable composite wood material from wood flakes; design, fabricate, and test poles made of this material; and analyze the economics of producing and marketing such poles. The basic raw material can be either wood residue generated at lumber mills or rejected tree species that have little commercial value. The supply of these raw materials will be far less critical than the solid roundwood poles now used and will be unaffected by length requirements.

Treating In-Service Wood Poles

Oregon State University is the contractor on a project to study the use of volatile chemicals to control biological deterioration in wood poles with volatile chemicals (RP212). These efforts were started before the establishment of EPRI and are now cofunded by the contractor, Pacific Power and Light Co., and EPRI. Specific objectives are to (1) develop methods to predict the need for supplemental treatment of wood poles in service, (2) develop effective formulas and methods of application of fumigants, (3) determine the fate and residual fungitoxicity of selected fumigants and their decomposition products in wood, and (4) determine the role of microorganisms in the reinfestation of fumigant-treated wood poles and the influence of nondecay organisms on the reestablishment of decay fungi.

Because the early activities in this project took place in the Pacific Northwest, most progress has been achieved with poles of Douglas fir. With the cooperation of 10 utilities across the country, the studies will be expanded to include western red cedar and southern yellow pine poles.

The status of this project can be summarized as follows:

□ Internal decay of Douglas fir poles can be controlled by pouring liquid fumigants into holes in the wood, which are then plugged. The fumigants diffuse as gases to eliminate decay fungi. If 2 pints of chemical per pole are used, retreatment cycles will be about six years with Vapam and longer with Vorlex and Chloropicrin.

□ Bioassay techniques that were successful in detecting decay fungi in cores from Douglas fir are not suitable in pine and cedar. Other techniques are being explored.

□ Correlation has been obtained between an agar-stick breaking-radius test and the longer, more complicated soil-block weight-loss test to determine the ability of decay fungi to degrade wood.

□ A "zone of inhibition" bioassay can be used to estimate the residual protection in poles treated with pentachlorophenol or other waterborne preservatives. The correlation between this and preservative content permits identification of poles in need of supplemental treatment before decay occurs.

□ Douglas fir poles treated with Chloropicrin and Vorlex for control of internal decay show that the chemical is still present in fungitoxic concentrations after six years. One year after treatment with Vorlex and Vapam with Hollow Hart, decay fungi were almost eliminated from Douglas fir poles.

Reinfestation of Douglas fir poles treated with Chloropicrin may be retarded further by the presence of a scytalidium species of fungi that is resistant to Chloropicrin and antagonistic to decay fungi.

Tree Regrowth Inhibitors

Two methods of chemical application to control tree growth are being studied. A pressure-injection method is being used by USDA–Nursery Crops Research Laboratory of the Agricultural Research Service at Delaware, Ohio (RP214). The University of California at Davis (RP380) is using a bark-banding method. Because of the different application methods, different chemicals are more appropriate for each method. Neither project has been expanded to include an exceptionally large variety of species. Each has started with the species locally available. Both projects employ a greenhouse study of seedlings to demonstrate effective chemical selection and concentrations, followed by field application and observations.

Results to date in a project on new methods and chemicals to control tree regrowth (RP214) have shown considerable progress. Seven chemicals in a variety of concentrations have been evaluated for their (1) ability to restrict regrowth, (2) effect on foliar appearance, (3) sprout activity both in quantity and length, and (4) ability to kill. Four chemicals were eliminated because they were either ineffective in limiting growth or caused excessive foliar decline or death of the tree. Field injections have been made and one- to two-year evaluations have been completed on American elm, Siberian elm, American sycamore, silver maple, and red oak. Additional greenhouse studies continue on live oak, white oak, white ash, Norway maple, eucalyptus, white pine, cottonwood, and poplar.

Portable, compressed-air powered equipment has been developed to inject a highly concentrated growth regulator solution. A commercial prototype should be ready for testing in other geographic areas as well as in urban areas by 1977. Evaluation of other regulators continues this year, and studies of the translocation and fate of injected growth regulators will be expanded.

There has been no progress report issued by the University of California at Davis on the field-applied bark-banding technique. Results from the earliest field bark-banding applications are now being tabulated for trees that have completed their first growing season. Greenhouse seedling experiments have established one chemical concentration suitable for good control. Others are under investigation.

Additional determinations to be made both in the greenhouse studies and in field trials include band versus size of tree relationship, solvents for the chemicals selected, and concentrations to be used. Field applications will provide data to determine optimum treatment time, aids that will improve absorption, bark characteristics that will enable us to predict species response, and the effect on appearance and vitality of several species. *Project Manager: Robert Tackaberry*

SYSTEM PLANNING

Research in system planning seeks to provide improved techniques for assessing future system requirements, including generation and transmission construction needs. This research is important because of the high capital cost of equipment and the new restrictions on growth resulting from social, environmental, and financial pressures.

Seven projects now under way are developing various planning and modeling tools for setting future system requirements. One project, load simulation models (RP849), was discussed in the July-August issue of the JOURNAL.

To assess future high-capacity transmission options, a recently completed project (RP568) with Commonwealth/Gilbert Associates analyses transfers of 2–5 GW over distances of 5, 50, and 200 miles. The first objective of this project was to identify the systems with relatively high economic potential and thereby enable EPRI to establish research priorities and advantageously assign R&D resources. The second objective was to segregate major cost components and to highlight areas where cost reductions are attainable. Growth projections show that after 1985 transmission systems capable of carrying up to 5 GW will be needed. This study identifies the important cost components of these systems in a consistent manner. Systems considered include: overhead, on-the-ground, and underground circuits; taped, extruded, gas-insulated, and cryogenic cables; and ac/dc lines. Both capital and operating costs are estimated.

The planning of power system installations may be based on dynamic system simulations. A project with Boeing Computer Services is developing a high-level diagnostic computer program to improve the efficiency of dynamic simulations (RP670). The resultant reduction in computer simulation time could greatly enhance the practical application of newly developed computer programs. This project should result in a quantitative description of the trade-offs among simulation accuracy, speed, and model complexity. It should also provide guidelines for selecting the best numerical techniques for system stability studies.

Dynamic instability (e.g., low-frequency oscillations), prevalent in the western and midwestern states, frequently causes operators to alter generation schedules to bring oscillations under control. On a few occasions, oscillations have been sufficient to trip lines and isolate subsystems, with consequent loss of load. In some power systems, oscillation problems impose restrictions on the generation schedules and on the transfer of power through tie-lines, thus degrading system operating economy and reliability. A project with Westinghouse Electric Corp. is developing a new technique for the analysis of low-frequency oscillations in large power systems (RP744). This research, called frequency domain analysis, should produce new analytic methods and new computer programs to alleviate oscillation problems.

Power system breakup can result from a combination of cascading events that occur within a few seconds to several minutes after a major disturbance, such as the loss of a major tie-line. Currently available "short-term" stability programs can practically simulate system behavior for only up to 20 seconds after the disturbance. A research project with Arizona State University is developing a "mid-term" computer method that will accurately simulate system behavior about 1 minute after a disturbance (RP745).

Arizona Public Service Company and Arizona State University have jointly completed the preliminary development of the research under RP745 and the project will be coordinated with another on long-term dynamics, that extends the study range to 20 minutes after a disturbance (RP764).

The long-term dynamic phenomenon is characterized by a large mismatch between load and generation in a utility system caused by the loss of major tie-lines, generation, or loads. There are numerous, well-documented cases where such a phenomenon has led to large variations in system frequency and voltage, and in some instances to cascading system failures, which resulted in widespread loss of load and generation. A project with General Electric Co. (RP764) will develop a digital computer program for simulating long-term power system dynamics in order to develop preventive measures. In the next step, a number of host utility systems will provide system data for an acceptance test. This will validate the computer program against actual system disturbance records, after which it can be released to the industry.

The utility industry has been spending several million dollars each year for computer costs in transient stability studies. A project with Systems Control, Inc. (RP763), if successful, will significantly reduce the computer time needed for transient stability studies. In an earlier EPRI-funded research project, Systems Control successfully developed a computer program to reduce the full-size representation of a power system to a smaller equivalent representation while maintaining simulation accuracy (RP904-1). The current project will significantly improve and totally automate the reduction process. This will require less computer time and thereby provide a practical tool for planning engineers. *Program Manager: P. M. Anderson*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

ELECTRIC UTILITY RATE DESIGN STUDY

In late 1974 the National Association of Regulatory Utility Commissioners (NARUC) asked EPRI and the Edison Electric Institute (EEI) to study the technology and cost of time-of-day pricing. The resultant joint effort, which has been under way for about eight months, includes an appraisal of various methods of controlling the peak period uses of electricity and a study of the feasibility and cost of shifting various types of loads from peak to off-peak periods.

The *Plan of Study,* which has guided all research activities to date, was prepared by representatives of EPRI and EEI and is being conducted by several consultants and 10 task forces. The plan focuses on the control and management of peaks—including the possibility of lessening electric system peak demand growth—and the economic role of pricing in managing load growth, which calls for a careful evaluation of peak load pricing.

The study examines the implementation of peak load pricing by means of alternative costing methodologies, namely, average and marginal costs. It is particularly noteworthy that the *Plan of Study* provides for a consideration of incremental costing for ratemaking within the limitation of aggregate revenue requirements determined by traditional costing methods. The plan affirms the concept of basing rates on the cost to the utility of providing service within the regulatory "just and reasonable" standard.

The *Plan of Study* was divided into 10 research topics:

- Various pricing approaches
- Elasticity of demand
- Rate experiments for smaller customers
- Costing for peak load pricing
- Ratemaking
- Cost advantages of peak load pricing
- Metering
- Technology for utilization
- Mechanical controls and penalty pricing
- Customer acceptance

A few preliminary observations, based on initial reports of the task forces and the consultants, may be of interest.

Various Pricing Approaches

Both the task force and National Economic Research Associates (NERA) have completed a state-of-the-art review of electric utility ratemaking in the U.S. While the task force has assembled the rate histories of a score of utilities for the 50-year period 1925–1975, NERA's report provides a historical overview of ratemaking practices in the U.S., with particular emphasis on the interplay between regulatory objectives and rate design. NERA has also prepared a review of rate-setting theory and practice in Britain and France.

NERA and Ebasco Services, Inc., as well as the task force, have prepared reports on the theoretical core of the rate design study (i.e., methodologies for time-of-use pricing in the U.S.). In brief, NERA sets forth a framework for marginal cost-based, time-differentiated rates. Ebasco developed alternative approaches to peak load pricing, based on several costing methodologies, which include both an embedded cost approach and a marginal technique. The task force has completed its interim report and has outlined its thoughts on peak load pricing based on average embedded costs.

Elasticity of Demand and Rate Experiments

The task force has completed a survey of the studies on demand elasticity for electricity and has concluded that the existing studies shed little light on the likely response of customers to time-of-day rates. The task force notes the need for substantial experimental efforts to develop methodologies for estimating elasticity at peak, as well as to gather empirical data.

NERA and J. W. Wilson & Associates have prepared reports on elasticity of demand. The task force has identified and is monitoring some 40 different experiments. Based on this work, decisions on the need for and specification of further experimentation will be made. These efforts will be necessary to reduce the uncertainty about customer response to peak load pricing.

Costing and Ratemaking

Seven utilities have been selected for detailed work on these topics, which are the most costly and time-consuming of the study. Both Ebasco and NERA are working with the utilities to develop alternative costing methodologies for peak load pricing. The data collection portion of these efforts has been completed.

The task forces have been working closely with the consultants and are providing a critical appraisal of their costing methodologies and ratemaking approaches. In addition, the ratemaking task force has prepared a preliminary report that describes its analysis of peak load pricing. Further, both NERA and Ebasco are developing time-differentiated rates.

At this point in the study, it is clear that the objectives of rate design are an important preliminary to the consideration of alternative costing and ratemaking approaches. Further, the concept of time-differentiated costs appears to enjoy broader support than might be expected. The problem is one of implementation, specifically in the measurement of costs and the metering of consumption.

Cost Advantages of Peak Load Pricing

This effort focuses on the development of methodologies for assessing the costs and benefits of load shifting. Under this topic, four consultants have been retained to work closely with the task force and the four participating utilities. Each consultant is developing its own model within the context of one of the four utilities.

Meters, Equipment, and Controls

One task force has completed an extensive survey of metering equipment. In addition, Arthur D. Little, Inc., (ADL) is analyzing alternative metering configurations, assessing equipment that could take advantage of peak load pricing, and appraising load control devices. The task forces have surveyed the literature and have assembled technical reports that assess the engineering aspects of shifting or controlling loads.

Customer Acceptance

This topic involves the assessment of customer attitudes toward electric utility rates. Elrick & Lavidge, Inc., has completed a national survey of residential, commercial, and industrial users of electricity. A preliminary report indicates an awareness of peak problems and an understanding of time-of-use pricing. In addition, a task force has evaluated the literature in this field.

Reports Required

The *Plan of Study* specifies three types of reports: quarterly progress reports, an interim report, and a final report. Progress reports were submitted to NARUC in March, June, and September. The interim *Overview Report,* which will be submitted to NARUC in late October, will describe the major issues and indicate the progress of research in the 10 topic studies. A verbal updating at the NARUC annual meeting is planned for November 16.

The final report will integrate the findings in the various topics and is planned to be submitted to NARUC in March 1977. It will include an assessment of the overall results and a recommendation on the directions that the industry and its regulators might follow. It seems quite likely that a comprehensive experimental program will be necessary.

Anticipated Results

The design of electric rates is being explored both extensively and intensively. There is tentative support for the idea that the most valuable electric service—power delivered at the time-of-system peak—is the most costly, and under current rate practices, it is underpriced. This may result in a generation mix and system expansion decisions that are not economically optimal. Whether the cost of improving the price signals is greater than the possible benefits is the heart of the rate design question—and this must be faced by each utility and each regulatory commission.

In July NARUC requested continuation of the joint study for a second year. The EPRI Board of Directors will consider the proposal at its November meeting.

ENVIRONMENTAL ASSESSMENT DEPARTMENT

Effects of Sulfur Oxides on Humans

Better understanding is needed of the effects on human health of emissions from fossil fuel combustion. A fundamental difficulty is our necessity to deal with possible exposure of large populations to low levels of pollutants which may have effects that are very difficult to detect. Estimates of the relationships between health effects and exposure, therefore, have inherent uncertainties. Nevertheless, decisions must be made that involve considerable cost for industry and government for emission controls and research. While sponsoring some contractual research in this area, EPRI's major effort so far is the planning of a comprehensive research program, coordinated with federal and other agencies. To initiate this effort, EPRI held a Workshop on Health Effects of Fossil Fuel Combustion Products *(1)*. Following the workshop, several projects were undertaken to assess past research, studies under way, and research plans of other groups. The National Research Council (National Academy of Sciences) under RP809 and Greenfield, Attaway & Tyler, Inc. (RP681) are performing these tasks and are advising EPRI on the research needs in this area.

Greenfield, Attaway & Tyler has reviewed the topics of research and analysis for which information is needed before optimal levels of control can be set for sulfur oxides. The review determined the adequacy of the existing data base and what data are critically needed to assess the hazards of ambient sulfur oxides.

To determine the health hazards of sulfur oxides, a good data base is required both for ambient measurements and for epidemiological studies. Current knowledge of the emission sources and the network of existing monitoring stations is relatively adequate for SO_2 and SO_2 plus particulates. But data are still inadequate for sources, and for chemical and physical characterization, as well as for formation of the other sulfur oxides, such as sulfuric acid, sulfates, and sulfites. Only cursory judgments can be made about human community exposures to ambient sulfuric acid, sulfates, or sulfites until such data have been acquired.

A review of the available information for specific sulfur oxide compounds suggests the areas where more research is needed. Information about SO_2 health effects is reasonably adequate and indicates that currently accepted safe levels are defensible, but only in the sense that SO_2 is regarded as an indicator of the harmful substances. There are no data available that would justify raising or lowering the present SO_2 standard, which was set in 1971 on the basis of limited and incomplete information. Some critical data on sources, transformation, and fate of SO_2 are missing, and EPRI is taking steps to fill these gaps (*2*).

Because most evidence indicates that the toxic potential of SO_2 is linked with particulates that are present with SO_2 and may interact with it, data based on SO_2 alone are insufficient. This condition prevents the establishment of defensible standards for the combination of SO_2 and total suspended particulates until more research results are in. Sufficient physicochemical characterization data are also lacking. Research priorities include the accumulation of more information about the products of interactions between SO_2 and particulates, their distribution in the environment, and their fate, as well as a greater understanding of the human health impacts of SO_2 in the presence of particulate matter.

Data on sulfuric acid levels in ambient air are likewise insufficient to allow the setting up of rational standards. Similarly, with the exception of data from animal toxicological studies, health effects information on the atmospheric presence of H_2SO_4 is almost nonexistent. Recent findings suggesting the presence of sulfuric acid in fossil fuel generating plant emissions indicate the necessity for further research.

Research priorities include work on atmospheric sulfuric and sulfurous acid mists, particularly in monitoring and in physicochemical characterization. On the effect-assessment side, there is a need for concise animal toxicological studies and investigation of controlled human exposure. Until better ambient exposure data are available, it is probably wiser to postpone epidemiological studies.

Because of indications that sulfates may be significant contributors to health effects, EPRI is supporting studies of the monitoring, physicochemical characterization, and fate of ambient sulfates, which will lead to future studies of sulfate effects in the areas of animal toxicology, human clinical exposure, and epidemiology.

A recent report by D. J. Eatough and A. V. Colucci (*3*) suggests that sulfites need to be given more attention as a potential health irritant. Theoretically, biological mechanisms exist that could explain the relationship between adverse health effects and sulfite exposure. Analyses indicate that sulfite concentrations are well correlated with sulfate levels where it has been suggested that the latter affect health. In general, however, meager information is available about sulfites. Similarly, data on the interaction of sulfur oxides with other pollutants, such as NO_x, CO, hydrocarbons, and oxidants, are scarce or lacking. Work is needed to identify sources, set up monitoring methods, and expand animal toxicological studies of the effects of sulfites, as well as the interaction of sulfur oxides with other pollutants. *Project Managers: Cyril Comar, Ronald Wyzga*

References

1. *Conference Proceedings: Workshop on Health Effects of Fossil Fuel Combustion Products,* May 1975. EPRI SR-11.

2. "Design of a Sulfate Regional Experiment." EPRI JOURNAL, February 1976, p. 46.

3. *Determination and Possible Public Health Impact of Transition Metal Sulfite Aerosol Species.* Topical Report for RP681, prepared by Greenfield, Attaway & Tyler, Inc., July 1976. EPRI EC-184.

ENERGY SUPPLY

Coal Mining Cost Models

A major goal of the Energy Supply Program is to assess the future relationships between prices and production levels of coal. A basic step in this assessment is the development of a way to estimate the cost of mining coal.

Coal production cost models for both underground and surface mines have been developed for EPRI by the NUS Corp. (RP435). These engineering cost models draw on the mining engineering capability of NUS and Pennsylvania State University and the systems analysis experience of NUS. They are not designed to give the precise production cost estimates required for designing a specific mine or for contract negotiation; they are intended rather to give a good approximation of cost for use in coal supply analysis, where many factors other than mining costs (e.g., government policy, prices of substitutes) reduce the need for precise estimates.

As defined in these models, costs include all expenditures directly associated with the mining and preparation of coal (e.g., normal taxes and profits) but exclude lease acquisition costs, royalties, severance taxes, and similar items. Such

Equipment such as this continuous miner has helped to increase efficiency and lower costs of underground coal mining.
Photo courtesy Joy Manufacturing Co.

items are usually included in the selling price, but since they are determined primarily by factors other than the physical characteristics of the coal deposit, they are considered separately.

The underground mining model can be viewed as a programmed or systematic guide to coal mine costing. It incorporates cost engineering principles, mining engineering logic, and actual mining experience factors. The primary end product of the model is the production cost. Other relevant information and data generated by the model include the requirements and costs of labor, equipment, construction, mine development, supplies, and power.

One salient feature of this model is the wide range of variables that can be accommodated: mine type—drift, slope, or shaft; mining system—continuous, conventional, or longwall; mine size—yearly tonnage; mine life—years of production; coal haulage—belt or track; seam characteristics—roof and floor conditions, seam gradient, gas emissions, depth of cover, and seam thickness; working schedule—number of shifts per day and days per year; rate of return—expected return on capital; coal preparation—inclusion or exclusion.

The surface mining model uses a more flexible approach to equipment sizing and quantities, labor requirements, type of mining method employed, and other key factors. Inherently, it requires a somewhat greater interaction on the part of the user. In constructing the model, both "global" relations and "local" details were considered—the former to provide general principles, and the latter to account for the unique conditions in a given mine.

The physical/geologic inputs to the surface coal model are: seam thickness, depth of cover, surface topography, topsoil thickness, drilling rate of overburden, bucket or dipper fill factor, angle of spoil, swell of overburden.

Though presently designed for hand calculation, both models are being computerized so that the many calculations required to develop realistic supply curves from detailed coal resource information can be made. An additional use of the computerized versions will be to calculate meaningful bands of uncertainty about the cost estimates through the use of Monte Carlo or similar methods. Through a commercial time-sharing computer service, utilities and others will also be able to access the computerized versions of the models.

Currently, the models give a "snapshot" of production costs, but they must be able to respond to anticipated changes both in the relative cost of input factors, principally labor and capital, and in mining conditions. The mining industry's response to major changes in these factors has been to develop new technology. Econometric work will be conducted to learn more about the coal industry's past responses to changes in input costs, and the results will be included in future modeling work. *Project Manager: Thomas E. Browne*

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E Balzhiser. Director

ADVANCED BATTERY SYSTEMS

The purpose, objectives, and systems involved in EPRI's battery program are discussed on page 6 of this issue. The central theme of the four major battery development projects is the fabrication, testing, and evaluation of laboratory prototype cells. These laboratory prototypes, while rather small (20–150 Wh) at this stage, are intended to reflect the full-scale (1–10 kWh) design concept. Ultimate operating modes and environmental conditions are simulated in the test program. This approach not only allows major operating problems to be identified, but through a complete posttest analysis, provides clues to the causes of the problems. The prototype cells permit systematic investigation of the effects of design as well as material and operational variables on the cell performance. Also important is that the general status of the battery technologies can be determined by comparing size, life, and performance of the laboratory prototypes with the projected specifications of the full-scale cell. Success in building and testing these laboratory prototypes justifies efforts on larger prototypes and, ultimately, full-scale cells.

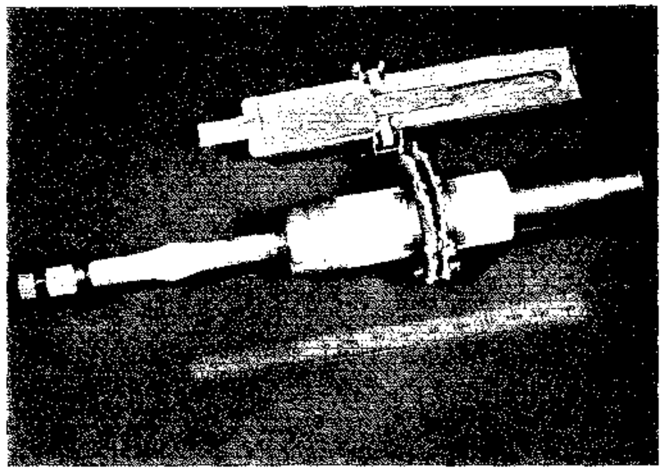
EPRI's four major battery development projects involve the following battery systems (batteries are usually named after their active electrode materials): sodium-sulfur, sodium–antimony trichloride, zinc-chlorine, and lithium–iron sulfide.

Sodium-Sulfur

Since the beginning of the development project in April 1973, General Electric Co. has used a 16-Ah (30 Wh) laboratory prototype cell (Figure 1). Improvements in electrolyte quality have provided an increase in the life of these cells by a factor of 4 over the past year to about 400 equivalent cycles (having a cumulative charge of 650 Ah/cm^2 electrode area). At the same time, the average useful capacity has been increased from about 50% to about 85% utilization of active materials with the new current collector designs in the positive electrode.

Presently, degradation of the glass seal between the electrolyte and the separator limits life. This and related seal problems are being studied, involving substantial engineering work to achieve scale-up. If successful, a full-scale battery module

Figure 1 General Electric's 30-Wh prototype, showing sealed cell (bottom) and cutaway view (top). Sodium is in the reservoir on the left and inside the solid electrolyte tube. Sulfur is on the right and outside the electrolyte tube.



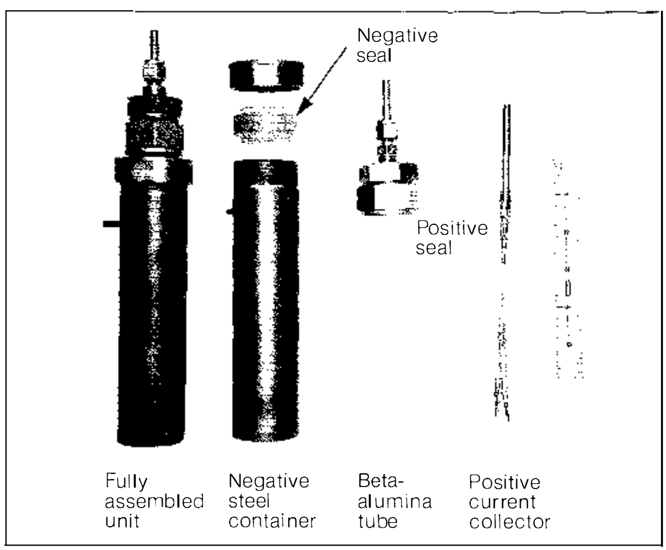


Figure 2 ESB's 20-Wh prototype, showing cell components. The positive active electrode material ($SbCl_3$ and $NaAlCl_4$) is inside the beta-alumina electrolyte tube and sodium is in the annulus between the electrolyte and the steel container.

will be fabricated and tested in 1978. This 100-kWh unit will be composed of about 50–100 full-scale cells and is anticipated to be the type of equipment that could be trucked to a distribution substation as the basic building block of a utility battery system. The 32-month effort, which concludes in 1978, will involve an EPRI expenditure of $2.5 million with nearly equal General Electric support for its in-house parallel program.

Sodium–Antimony Trichloride

Cell development and testing activities by ESB, Inc., over the past calendar year have involved transition from small test cells (1–2 Wh) with disc-shaped, solid electrolytes to tubular cells (10–20 Wh) having a design representative of the full-scale cell (Figure 2). The life of disc cells has been extended to 18,000 hours and 700 cycles (240 Ah/cm^2), and the life of laboratory prototype tubular cells is 4000 hours and 175 cycles (30 Ah/cm^2). The longest-lived cells are still on test.

The long life of the disc cells shows the basic compatibility of system components. However, electrolyte failure has so far prevented tubular cells from consistently achieving long life. Work is presently directed toward improving electrolyte quality and, therefore, cell life. The existing one-year, $610,000 EPRI–ESB-funded project calls for fabrication and testing of a multitube 1-kWh cell early next year.

Zinc-Chlorine

Since the zinc-chlorine system was in a more advanced stage of development, EPRI's first effort (1974–75) with Energy Development Associates (EDA) involved the fabrication and testing of a 1-kWh cell system for 100 cycles (Figure 3). That phase was successfully completed. This year's $1.1 million effort—jointly funded by EDA and EPRI—is devoted to longer-term testing of a 1-kWh cell, performance testing of full-scale (2kWh) cells, and fabrication and initial testing of a 20-kWh (10-cell) battery system. Much of the present work is devoted to optimizing the operating conditions (current density and temperature), battery design, and component materials to obtain the lowest possible costs.

System automation, including continuous electrolyte purification, remains a major development step. If technoeconomic evaluations of the system continue to show promise, next year's effort will probably involve demonstration of a 100-kWh (50-cell) battery system.

Under a separate contract with ERDA, EDA will deliver two 25-kWh batteries (electric vehicle size) for test and evaluation in 1977–78.

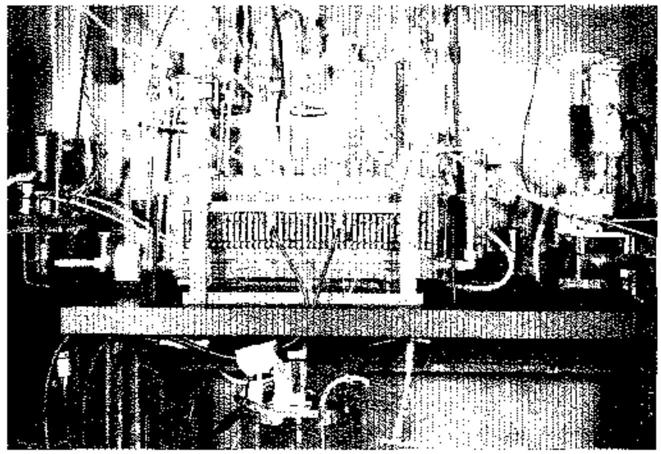
Lithium–Iron Sulfide

Since the EEI–EPRI project was initiated at Atomics International (AI) in February 1972, there has been a gradual shift from liquid lithium and sulfur electrodes to solid lithium-silicon and iron-sulfide electrodes. This change was necessary to eliminate capacity degradation caused by migration or dissolution of electrode materials into the electrolyte. There was concern, however, that degradation of the solid materials would be inherent as a result of detrimental morphological changes common with such battery electrode materials. Progress over the past 18 months in the joint AI–ERDA–EPRI project has, so far, tended to disprove this.

AI has operated a 150-Wh cell for nearly 1000 cycles and 10,000 hours. Although the cell operated with little change in performance for most of the test period, capacity and coulombic efficiency dropped somewhat during the last several hundred hours. Nevertheless, the cell has operated longer than any other high-temperature prototype cell. Causes of the performance degradation are now being investigated.

In addition to this cell, AI has recently begun testing a 300-Wh cell that employs 22.9 × 22.9 cm full-scale electrodes.

Figure 3 EDA's 1-kWh prototype, showing cell containing 80 electrode pairs (center), chlorine hydrate store (left), and auxiliary subsystems.



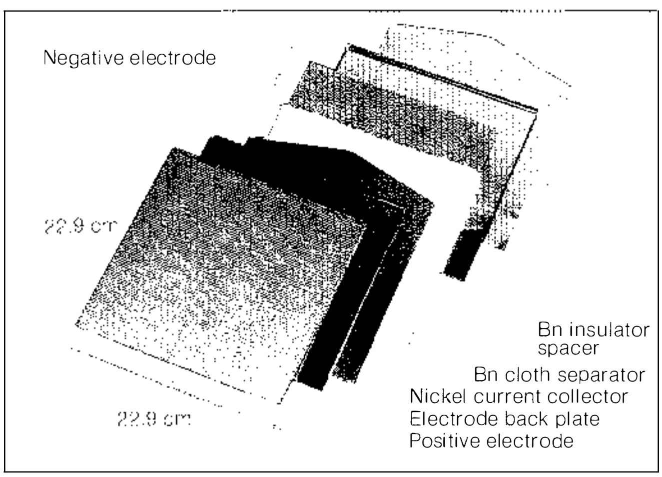


Figure 4 Components of AI's 300-Wh laboratory prototype cell.

Initial results show that the cell's performance has met nearly all the design targets. The components of the 300-Wh cell are shown in Figure 4. The present schedule calls for testing a 1-kWh cell by October of this year. Next year's $1.0–$1.3 million project will involve fabrication and construction of a 2.5-kWh full-scale, load-leveling cell.

Project Emphasis

The schedule for EPRI's battery developers now calls for a shift in project emphasis from research and exploration to hardware development and optimization. The laboratory prototype cell provides the major link between these two stages of R&D. Although use of these prototype cells might be considered a rather Edisonian approach, the research has laid the groundwork for most of the recent advances in battery technology. Over the next year, full-scale cells (representing most of the major battery system candidates for utility application) will be built and testing will be initiated.

If progress continues on the prototype cells and if the full-scale cell performs as well as have the prototypes (as is expected) we will feel confident to proceed with testing 1–10 MWh batteries in the Battery Energy Storage Test (BEST) Facility. One major remaining hurdle is the question of economics. The economics of utility battery systems will be discussed in a future JOURNAL progress report. *Project Manager: Jim Birk*

CLEAN GASEOUS FUELS

Combined-Cycle Systems

The resource utilization and emission characteristics of gasification—combined-cycle (GCC) plants offer the greatest opportunity for gasification-based electric power systems. By removing the emission-forming constituents prior to combustion, clean gaseous fuel systems offer advantages over direct coal firing with stack gas scrubbing. These advantages are illustrated in Table 1, which compares the environmental impact of 1000-MW power plants based on the two technologies—pulverized-coal firing plus stack gas scrubbing (PC + SGS) and GCC. Because it is likely that more stringent emission control regulations will be applied to power plants in the future, the advantages cited in the table are considerable.

The direct coal-fired unit requires hauling and storing 50% more raw material and is estimated to consume about 50% more water. The extra land area required for sludge disposal could be as much as five times that of a GCC unit, depending on specific circumstances. In addition to better resource use, these factors also indicate that the choice of new sites or the possibility of reusing old sites is greatly increased with the GCC technology.

Table 1

ENVIRONMENTAL IMPACT OF 1000-MW POWER PLANTS

	Pulverized Coal Boiler + Stack Gas Scrubber	*Gasification–Combined-Cycle*
Coal consumption (lb/kW)	0.87	0.70
Limestone required (lb/kW)	0.15–0.20	0
NO_x emissions (ppm)	500	10–40
SO_2 emissions (ppm)	200*	10–200
Particulate emissions (g/ft³)	0.01	Unknown (probably lower)
Makeup water	0.6–0.65	0.4–0.45
Disposal land (acres)	1200–2400	200–500

*Could be further reduced to 10 ppm by an additional scrubber stage, estimated cost $50–$75/kW.

Table 2

FLUOR FUEL GAS STUDY

System	*Capital* (\$/kW)*	*Cost of Services 70% load factor*	*\$/million Btu 90% load factor*
Pressurized fixed-bed dry ash			
Air	652	3.78	3.19
O_2	806	4.42	3.71
Pressurized ash-agglomerating fluidized bed			
Air	426	2.69	2.31
O_2	400	2.57	2.23
Atmospheric two-stage entrained slagging			
Air	376	2.48	2.13
O_2	385	2.69	2.38

*The equivalent kW is the by-product power plus the potential power that could be generated by burning the product fuel gas and liquid hydrocarbons in a plant having a heat rate of 9000 Btu/kWh. The capital includes the cost of generating equipment required to produce by-product power but excludes the cost of the power plant required to produce the potential power.

Economic Studies

A report for EPRI has recently been completed by Fluor Engineers and Constructors, Inc., covering both air and oxygen gasification in pressurized fixed-bed dry ash, pressurized ash-agglomerating fluidized bed, and atmospheric two-stage entrained systems for the production of clean fuel gas. The design basis was for a plant feed rate of 10,000 t/d of Illinois No. 6 coal.

The process data for these studies were provided by the American Lurgi Co. for the fixed bed, by the Institute of Gas Technology for the fluidized bed, and by Combustion Engineering, Inc., for the atmospheric entrained gasifier.

The fixed-bed cases are representative of current commercial technology, whereas both the fluidized bed and the atmospheric entrained cases represent technologies under development. If developed as planned, the advanced gasifiers should be able to reduce the cost of fuel gases to 60–70% of the cost with current technology (Table 2).

It also appears that air gasification is more economic for the pressurized fixed-bed dry ash and is slightly better for the atmospheric entrained system, whereas the costs of air and oxygen blowing are very similar for the fluidized bed.

Fluor is currently conducting further engineering studies of these and other advanced gasifiers in integrated combined-cycle systems. A report on this work should be issued by the end of 1976.

In another EPRI-sponsored study, Stone & Webster Engineering Corp. has compared the cost of both hot and cold gas cleanup for removal of particulates and H_2S in several gasification processes. The purpose was to determine the economic incentive for developing high-temperature gas cleaning systems. The gasifiers examined were the Lurgi pressurized fixed-bed dry ash, with air and oxygen blowing; the oxygen-blown British Gas Corp. (BGC) pressurized fixed-bed slagging gasifier; and the Foster-Wheeler Energy Corp. pressurized two-stage entrained gasifier for both air and oxygen blowing. Each gasifier was integrated with a combined cycle. Two gas turbine inlet temperatures of 1950°F and 2400°F were considered.

While it is recognized that hot gas cleanup systems are at a very early stage of development, these studies show that such a system, if developed as planned, would markedly improve the efficiency and cost of a Lurgi combined-cycle system, mostly by permitting the by-product liquids to be burned in the turbine. However, hot gas cleanup showed very little improvement in the cost and efficiency of the BGC slagging gasifier and the Foster-Wheeler two-stage entrained-gasifier–combined-cycle systems. It therefore appears that the incentive for hot gas cleanup system development is not as great as other sources had previously indicated.

These studies also show that the cost of power from GCC systems based on the BGC slagging gasifier or the two-stage entrained gasifier should be competitive with that from PC + SGS systems.

Development Program

Large gasification–combined-cycle plants of 500–1000 MW will probably be made up of multiple trains of about 200-MW capacity. Each train will probably contain a single large gas turbine.

A realistic appraisal of the necessary technological data for the design of gasification–combined-cycle demonstration plants of 200 MW, or greater, places their operation in the post-1985 period. Although under exceptional circumstances this development period could be shortened, it would obviously be at increased risk. The logical flow of information from project to project and through to the demonstration plants follows.

These systems require a high degree of integration between the gasifiers, cleanup train, and gas turbine and the steam system. Such integrated systems do not yet exist, and the dynamic response characteristics and required control system strategy are not yet known.

General Electric has recently completed a planning study for EPRI on the integration and control of such systems, which was based on the use of a simplified power system model, using a fixed-bed GCC plant. The study concluded that power system performance requirements should be achieved when operated in a gasifier follow control mode. However, this implies that the gasifier cleanup train must accommodate pressure changes, and it is not yet known if this can be accomplished. Several other control questions were raised by this study that cannot be answered with a simplified model. We therefore planned to undertake further studies based on a more detailed simulation model to provide better understanding of the interactive dynamics between components and the response capabilities of various GCC systems.

The results of these studies should be completed in time for the recommended control strategies to be tested and verified at the gasification–combined-cycle test facility (GCCTF) at Commonwealth Edison's Powerton station in Illinois. Negotiations for ERDA's participation in the GCCTF project are continuing, and if successfully concluded, the initiation of a three-year test program on the 25-MW fixed-bed facility is projected for the end of 1978.

General Electric's preliminary study points out that the GCCTF at Powerton would also serve to demonstrate many important generic control systems for GCC plants.

Following closely on the GCCTF project, another study on an entrained gasification system test facility is planned. The results from these system test facilities, together with the parallel gasifier developments in the ERDA demonstration plant program, will provide the information for design of GCC demonstration plants.

ERDA's Gasification Demonstration Plant Program

ERDA has issued requests for proposals (RFPs) for gasification demonstration plants. The first phase of the selected projects, which includes the demonstration plant design and some supporting R&D work, will be funded by ERDA. For phases 2 and 3 (construction and operation), 50% industry financing is expected. These projects will take about eight years for completion: two years for Phase 1, three years for construction, and three years of test operation. EPRI has not participated in the submission of proposals; however, if the projects selected are based on technology of interest to the power industry, EPRI may support them.

In October 1975, ERDA issued an RFP for high-Btu gasification demonstration plants. Five proposals were submitted, and in June ERDA announced the selection of two of these projects for contract negotiation. The top-ranked proposal was based on the BGC slagging gasifier technology and was submitted by Conoco and seven gas pipeline companies. The demonstration plant will use 3800 t/d of an eastern caking coal to produce 59 Mft^3/d of pipeline-quality gas. The project cost has been estimated at $410 million. EPRI has been cosponsoring the BGC slagging gasifier development at Westfield, Scotland. The latest results from these tests suggest that this technology, when linked with advanced air-cooled gas turbine–combined-cycle systems, could provide power at a cost competitive with that from direct coal firing with stack gas scrubbing.

The second selected proposal was based on the COED fluidized-bed pyrolysis technology linked to the fluidized-bed COGAS gasification process and was submitted by the Illinois Coal Gasification group (five Illinois utilities). The project would use 2000 t/d of Illinois coal to produce 18 Mft^3/d of pipeline gas and about 2000 bbl/d of fuel oil.

In February ERDA issued an RFP for low-Btu (150–500 Btu/ft^3) gasification demonstration plants. Fourteen responses were submitted. Five were in the category of utility projects directed at electric power production: Combustion Engineering, Inc.; Environmental Recovery of America, Inc.; Foster-Wheeler Development Corp.; Louisiana Municipal Power Commission; and Nanticoke Industrial Development Corp. There were four responses in the industrial gas category: Ebasco Services, Inc.; IFG Co.; Memphis Light, Gas and Water Division; and LNG Services, Inc. The other five responses were in the small-scale industrial category. The selection should be made during the fall of 1976. *Program Manager: Neville Holt*

CLEAN LIQUID AND SOLID FUELS

EPRI is directing its efforts toward the solvent-refined coal, H-Coal, Exxon donor solvent, and fuel-grade methanol processes. These processes have the potential of producing (either directly or with subsequent product upgrading) a variety of clean utility fuels. These fuels range from methanol and light distillates to solvent-refined coal, which may be used as either a clean pulverized solid or a heavy liquid boiler fuel.

The major efforts of the Clean Liquid and Solid Fuels Program are aimed at the ultimate commercialization of one or more of these processes. However, a strong analysis and technical development subprogram exists to provide support for the major liquefaction programs in areas ranging from economic evaluation to product and process improvement. Three elements of this subprogram may be classified as direct liquefaction research (as opposed to the indirect production of a coal-derived liquid, e.g., methanol synthesis).

- *Basic Studies and Process Chemistry* These studies are directed toward providing a better understanding of existing processes and thereby pointing the way to solution of current processing problems or to process improvements. The results generated through these efforts will also aid in the development of second-generation processes.

- *Catalyst Development* This effort has as its immediate goal an improved catalyst that can be produced on a commercial scale in time for the first generation of large-scale catalytic coal liquefaction plants.

- *Product Upgrading* This encompasses such areas as improvement of the handling properties of utility boiler fuels and the further processing of primary liquefaction products to meet both environmental and end-use requirements.

Close coordination between these subprogram projects and the ongoing process development projects is maintained (to the extent that this is feasible) with samples generated in pilot plant operations used in the laboratory-scale investigations. Contractors working in the above areas represent industry, nonprofit research institutes, and universities.

Basic Studies and Process Chemistry

Mobil Research and Development Corp. is now in the second year of a detailed investigation of the chemistry of coal liquefaction (RP410). The efforts of this industrial contractor have been supplemented by subcontracts with University of California at Berkeley, Case Western Reserve University, and Princeton University. Emphasis has been on the basic properties of solubilized coals from major U.S. seams and their reactions under typical solvent-refining conditions.

A new two-step process has been identified that attains solvent yield and product sulfur content specifications at significantly lower reaction times, with lower hydrogen consumption than conventional solvent refining processing. Successful development of this second-generation process offers reduced fuel costs through reduced capital costs and lowered hydrogen use.

By employing synthetic recycle solvents that incorporate the important chemical species found in a process-generated solvent, Mobil is assessing the criticality of solvent chemistry on liquefying coals of different ranks to acceptable levels of conversions. Using special analytic tools, some developed specifically for coal liquids, Mobil has made significant strides in understanding the structure of coal and how that relates to its conversion and to the products formed. Certain product properties may be manipulated by proper adjustment of the processing conditions, rather than being set by the chemistry of the feed coal.

Other projects, with Gulf Research and Development Co., Stanford Research Institute, Pennsylvania State University, and the University of Tennessee, are investigating:

- The reactions of oxygen during hydrogenative liquefaction of feed coal
- The use of field ionization mass spectrometry to characterize and to control the quality of coal liquefaction products
- The autoadhesion of pulverized solvent-refined coal (SRC)
- The prevention of SRC reactor solids buildup that can force interruption in operation

Catalyst Development

Amoco Oil Co. is conducting a three-year program to develop an improved direct coal hydrogenation catalyst for H-Coal and other catalytic liquefaction processes (RP408). Screening of several commercial catalysts has been carried out to provide information on the performance of those materials currently available. Partially completed is a systematic study of catalyst composition, structure, and other parameters. Laboratory preparations made by Amoco are being supplemented by those made under subcontract to W. R. Grace & Co., a major catalyst supplier.

Although these short-term screening tests have identified several catalysts with superior initial activities, the final assessment of a catalyst's ability to maintain its performance must be made in the hostile environment encountered under actual liquefaction conditions. These catalyst-aging tests will be performed in a continuous small-scale reactor system now being brought into operation.

Product Upgrading

The Atlantic Richfield Co. has carried out a study to identify the chemical species and interactions responsible for imparting high viscosity to both catalytic and noncatalytic coal conversion products (RP626). As a result of this work, chemical treatments are being applied to provide economical approaches to disrupting the chemical interactions between the basic nitrogen and phenolic hydroxide-containing components, which are highly concentrated in a fraction of both H-Coal fuel oil and SRC. There is an indication some simple, low-cost additives may be useful to significantly reduce the viscosity of H-Coal boiler fuel.

In the first phase of a study (RP361) on upgrading coal liquids, Mobil Research and Development Corp. has identified process and quality problems that occur when raw and processed coal liquids are used as gas turbine fuels. Because little information exists on the use of coal-derived liquids in combustion gas turbines, much of the analysis was based on extrapolation of operating experience and specifications derived from the use of petroleum-based fuels.

The major conclusions derived from the Mobil study are:

- Compared with even the heavy residual petroleum-based turbine fuels, coal-derived liquids are hydrogen deficient.
- The nitrogen content of coal liquids exceeds the restrictions on fuel-bound nitrogen. Significant reduction of this element will be required for the liquids to meet environmental standards.
- Removal of trace metals (i.e., sodium and potassium) in some coal liquids will be required to prevent corrosion of the turbine blades.
- Raw coal liquids containing the higher boiling fractions are incompatible with common petroleum blending stocks. However, this incompatibility may be overcome with the proper processing or the removal of the offending species from the coal liquids.

Mobil is currently engaged in the second phase, which is directed toward developing a viable process or processes for upgrading coal liquids to gas turbine fuels. Various products from both the H-Coal and the SRC processes will be upgraded, using combinations of hydroprocessing, vacuum distillation, and solvent deasphalting. Westinghouse has been chosen as a subcontractor to perform small laboratory-scale combustion tests on selected coal liquids generated in this study. *Project Manager: William C. Rovesti*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

PEACH BOTTOM END-OF-LIFE STUDY

What can be learned from a reactor that is at the end of its economic life and about to be taken out of service?

Peach Bottom Unit 1 is providing answers in ways not possible while the reactor was still in operation. The primary objective of the end-of-life project is to document the performance of plant systems and materials by study of the plant itself and examination of materials cut from its equipment. The findings will be compared with the calculated results that would have flowed from a Peach Bottom 1-type plant built with today's design practice, so as to validate design methods for HTGRs. To increase the usefulness of the data, a detailed history of plant operating conditions—temperatures, pressures, power level, coolant activity, and the like—has been compiled, covering the 7½ years the unit was in service.

Peach Bottom 1 is a pilot-scale HTGR demonstration unit with a 115-MW thermal rating and a net output of 40 MWe. It was placed in commercial operation by Philadelphia Electric Co. in June 1967, and it functioned with notable smoothness until November 1974, when the utility decided it was too small for further economic operation. Under EPRI–ERDA sponsorship, the end-of-life project was started in February 1975, with a December 1977 target completion date. The contractor is General Atomic Co. (RP402).

On-Site Activities

The primary activities performed at the Peach Bottom site were gamma scanning of fuel elements, primary coolant ducting and steam generator tube bundles, and the removal and preparation for shipment of sample materials removed from the system.

The fuel element gamma scanning was performed by using a stationary detector located at a penetration of the shielding of the fuel charging machine. Axial scans were obtained by slowly withdrawing the fuel element into the charging machine. A high-resolution Ge(Li) spectrometer was used to obtain spectral distributions at each location. From this information, the concentration of various isotopes of different half-lives can be established and used to infer power distributions at different times in core life.

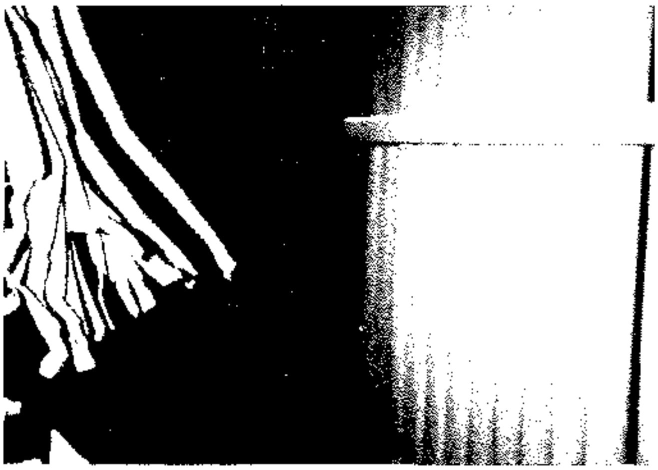
The activity distribution in the primary ducting was determined by using Ge(Li) detectors for external scans at 11 locations. Internal ducting gamma scans were also performed at two locations through openings in the duct wall in conjunction with the removal of duct samples. Longitudinal scans were obtained at these locations with a traveling detector.

The Peach Bottom steam generator design incorporated separate U-tube bundles for economizer, evaporator, and superheater sections, with water on the tube side and helium in crossflow on the shell side. The activity distribution in the steam generator for one of the loops was measured by small CdTe detectors traversing the inside of selected tubes. Mock-ups of small tube bundle sections with known activity distributions were used to calibrate the detectors and to validate methods for determining plateout distributions from measured gamma flux distributions.

The sample materials removed included trepan samples from selected duct locations, steam generator tubing samples, and a sample of steam generator thermal barrier and shroud material obtained during the removal of the steam generator shell to gain access to the tube bundles. A total of 31 trepan samples were removed from eight locations in the primary ducting. The samples were approximately 3 in. in diameter and were taken from positions around the circumference of the duct at each location. A total of 104 samples of steam generator tubing approximately 15 in long were removed from the evaporator, economizer, and superheater bundles by cutting through the steam generator shell.

On-site macroscopic examination of the steam generator provided visual inspection of conditions before major cutting activities. These examinations included borescope examination of the inside of selected superheater tubes, evaporator tubes, and chamberscope and direct visual observations of shell side conditions (Figure 1).

Figure 1 The postoperative appearance of Peach Bottom 1 steam generator internals (right) and thermal barrier foils (left) show no significant detrimental or unexpected features. The superheater tubes are a uniform matte dark gray; the fretting under the baffle plate is slight. The 2-mil stainless steel foils show good ductility after being cut.



Experimental Investigations at General Atomic

Testing and examinations presently being performed at General Atomic include radiochemical and metallurgical examination of samples and tritium permeation studies. These activities are organized to provide key information required for the validation of HTGR design methods and are scheduled for completion by the end of 1977.

Radiochemical examinations include gamma scanning of all samples removed from the primary circuit and steam generator. Results of these examinations will be used to provide absolute calibration for gamma scanning data obtained on site, as well as additional plateout information on beta emitters, such as strontium. Activation analysis is being used to determine concentrations of long-lived isotopes, such as ^{129}I and ^{126}Te, in selected samples. Decontamination studies are being performed to develop and test reagents and processes that are effective in removing deposited fission products from primary loop components.

Metallurgical examinations include microscopic examinations to evaluate the extent of oxidation and carburization on the helium side, water-side corrosion and stress corrosion cracking (if any), friction and wear damage on rubbing surfaces, and the degree of microstructural change due to aging effects of stress, temperatures, and time. Chemical analyses will be performed to determine changes in composition for cases where archive samples are available. Mechanical testing of selected samples includes tensile, rupture, and fatigue tests to determine changes in mechanical properties of sample materials. Preliminary results of microscopic examinations of the steam generator tube samples are shown in Figure 2.

Tritium permeation testing of steam generator tube samples is being performed to provide an improved basis for modeling the transport of tritium from the helium coolant to the water side of the steam generator. A mixture of tritium, helium, and normal impurity concentrations is used on the outside of tubing samples, with steam on the inside, to determine tritium permeation as a function of tubing temperature over the normal operating range for an HTGR.

Design Methods Verification

Present HTGR design methods will be applied to Peach Bottom Unit 1 plant parameters and operating conditions to predict conditions for comparison with experimental measurements. Core physics design methods for calculating power distributions will be checked against results of fuel gamma scanning (Figure 3). The calculation of heavy metal and fission product distributions will be compared with the results from postirradiation examination of Peach Bottom fuel elements being performed at Oak Ridge National Laboratory under an ERDA contract. Core thermal design methods will be checked against thermocouple readings taken during plant operation and against coated particle performance as determined by the postirradiation examinations at ORNL.

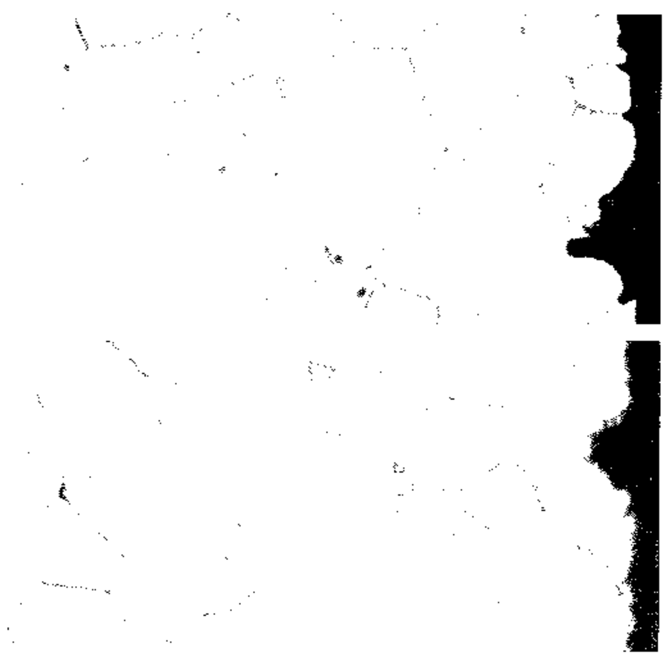
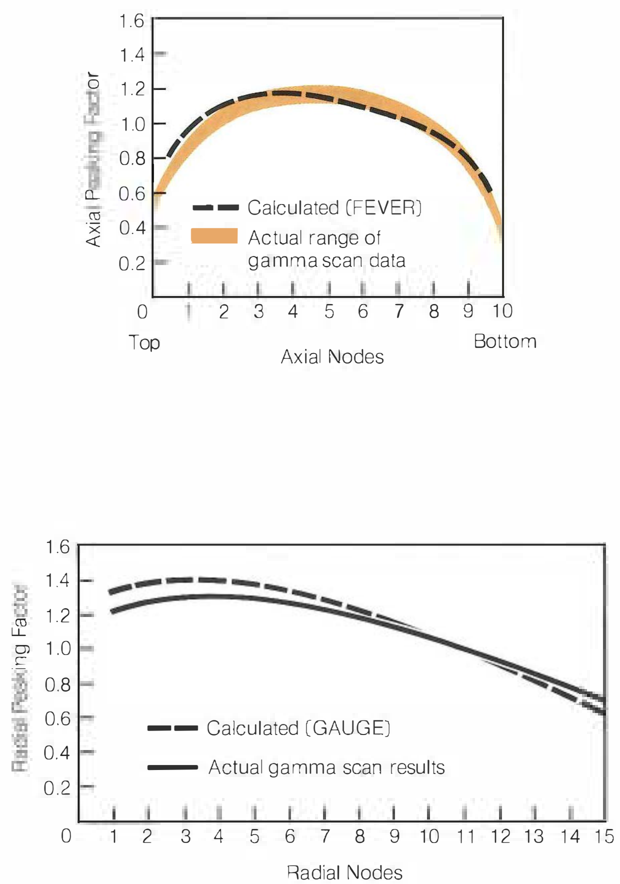


Figure 2 Cross sections of Incoloy 800 superheater tubes (500×) before and after service confirm the excellent performance of this alloy. The outer surface of an archive tube (top) is compared with the outer surface of a tube after 7½ years' service at about 1200° F.

Figure 3 Results from the nondestructive testing phase show very good agreement with core physics predictions. Here the calculated power distribution after 900 effective full-power days is compared with gamma scan results.



The fission products design methods verification is directed toward validation of predictions of fission product release from the core and plateout distribution in the system. The combined results of (1) gamma scanning and postirradiation examination of fuel and (2) gamma scanning and sample evaluations of primary ducting and steam generator internals will be used to establish fission product release from the core and distribution in the primary system.

Applicability of Results

The work being performed under this project will provide a stronger basis for the design, licensing, and operation of gas-cooled reactors. The results will be most directly applicable to the steam-cycle HTGR. However, portions of the results will also be applicable to other concepts, such as the GCFBR. Although the prognosis for commercial development of gas-cooled reactor technology is uncertain at present, the usefulness of the results, combined with the uniqueness of the opportunity for detailed postoperative examination of a plant, makes the results of this project a valuable contribution to nuclear technology in general. *Project Manager: James Kendall*

TWO-PHASE-FLOW MEASUREMENT TECHNIQUES

EPRI is currently funding a substantial number of research projects in the thermal-hydraulic aspects of nuclear reactor safety.

The design of reactors and the assessment of their safety is based on the use of complex computer codes to describe coolant behavior and heat transfer during off-normal operating conditions. These computer codes are tested for their validity against experimental simulation of reactor upsets in large-scale replicas of reactor systems and subsystems. The fluid state and behavior measurements are therefore important to the ultimate capability of the predictive codes.

Recognizing the pivotal role in reactor analysis of two-phase-flow instrumentation, EPRI has sponsored two state-of-the-art studies on the subject (*1*, *2*). A summary of the findings of those efforts and a definition of EPRI's role in the further development of two-phase-flow measurement techniques follow.

Pressure and Pressure Differential

For pressure and pressure-differential measurements, the diaphragm-type pressure measurement technique seems to be quite acceptable—at least as far as the transducing mechanism's frequency response and stability are concerned. What is needed, however, is the development of designs and operating procedures for using off-the-shelf pressure transducers in a manner to enhance their current performance features, as well as to avoid the adverse effects of the hostile environment of transient, two-phase, high-pressure, high-temperature experimental conditions associated with reactor safety tests.

Density and Void Fraction

A large variety of techniques have been proposed and used for measuring void fraction, reflecting its importance. For precise measurement (but restricted to near-steady-state conditions), quick-closing valves or the side-scatter gamma densitometer show good results. Radiation attenuation methods, including gamma densitometers, have proved themselves for large-field and high-pressure piping systems under transient conditions, in spite of their apparent radiation hazards to personnel and their cost. Contact probes of electrical impedance, fiber optics, microthermocouples, and hot-wire anemometers have been used successfully in laboratory experiments but are still limited in range and applicability.

Regime and Void Distribution

The general state of knowledge of flow patterns is unsatisfactory and improvement is needed in the development of better two-phase-flow models. The existing body of data relies heavily on visual or photographic techniques that are applicable only to laboratory-type experiments. Methods applicable to high-pressure, transient conditions and yielding more quantitative data are needed. The techniques that show the most promise at present are multibeam absorption and parameter fluctuation correlation.

Velocity and Slip

Fluid flow parameters of velocity and slip continue defying measurement by the application of fundamentally simple techniques. Velocity and density distributions in two-phase flow and their dependence on flow regime complicate the situation. Accurate results can be obtained if the upstream conditions are reproducible between the calibration and actual application. However, this requirement cannot be met in the majority of nuclear safety research experiments.

Liquid Level

The measurement of liquid level in a constant-temperature, constant-pressure environment is a relatively simple process. Under rapidly changing conditions, however, the limited heat capacity of the sensor and the froth above the liquid may result in ambiguous data. Further development and verification of liquid-level measurement techniques under transient conditions are required.

Future Research

As the role of experimentation in nuclear safety research is to develop and verify analytic methods, the measurement requirements change as analytic methodology advances. In the near term, because present analytic tools often assume homogeneous flow and average-volume quantities, instrumentation development must be oriented toward developing instruments to verify these analytic methods. The measurement of transient, two-phase, mass-flow rate has been identified as a high priority item.

In the longer term, as analytic methodology develops, more detailed measurement of flow phenomena will be required. Such quantities as flow regime and phase velocities and temperatures will become more important. *Project Manager: Rodney R. Gay*

References

1. *Experimental Methods in Two-Phase Flow Studies.* Final report for RP446-1, prepared by Atomic Energy Research Establishment (Harwell, England), March 1976. EPRI NP-118.

2. *Single-Phase and Two-Phase Flow Measurement Techniques for Reactor Safety Studies.* Topical Report for RP694-1, prepared by Intermountain Technologies, Inc., July 1976. EPRI NP-195.

NUCLEAR CROSS SECTION DATA BASE

A nuclear cross section is the probability that a certain type of reaction, such as fission or radiative capture, will occur when the nuclei of an element — ^{235}U, for example — are bombarded by neutrons or other light nuclides.

The main objective of EPRI projects relating to cross sections continues to be the development of a national standard based on the Evaluated Nuclear Data File (ENDF/B) system. For this reason, all EPRI cross-section projects have been closely coordinated with the activities of the ERDA–EPRI Cross Section Evaluation Working Group (CSEWG), which is responsible for the contents of the ENDF/B library.

EPRI is giving priority to the following areas.

- Testing of the present version of the library (ENDF/B-IV) in calculations of critical lattice experiments
- Review and extension of the set of experiments considered as thermal-data testing benchmarks by CSEWG
- Development of new or revised evaluations for nuclides of particular importance to thermal reactor applications

In a recently completed project (RP220), a set of light- and heavy-water-moderated critical lattice experiments has been analyzed by Brookhaven National Laboratory (BNL). This analysis has shown that the discrepancies observed with earlier versions of the library (1–2% underestimate of eigenvalues, 10% overestimate of capture rates in ^{238}U) are reduced by about 40% when the new ENDF/B-IV data are used in conjunction with the very accurate transport theory and Monte Carlo methods.

A further improvement in the correlation between calculations and experiments has resulted from a project with Stanford University (RP247). This was a detailed study of the procedures used by experimenters in deriving values of reaction ratios from their measured foil activation data. Ratios such as ρ^{28} (epithermal-to-thermal capture rates in ^{238}U) or δ^{25} (epithermal-to-thermal fission rates in ^{235}U) obtained from foils activated in lattice experiments must be corrected to account for the perturbations introduced by the foils, their cadmium covers, and other experimental apparatus. When the original correction factors were recalculated by the Stanford group with the use of more recent cross-section data and more accurate Monte Carlo methods, the resultant revised experimental values were, in general, found to be more consistent and in better agreement with results calculated at BNL (RP220) and other laboratories participating in the CSEWG effort.

Both the BNL and the Stanford studies, which were limited to slightly enriched (1.3%) or natural uranium systems, will be extended to plutonium and mixed-oxide-fueled lattice experiments in two one-year projects (RP708 with BNL and RP830 with Stanford). These new projects will be responsible for the analysis and review of the mixed-oxide critical lattice experiments at the plutonium recycle critical facility of Battelle, Northwest Laboratory (RP348).

The next version of the ENDF/B library is expected to contain a number of new or revised evaluations produced under EPRI support. In particular, the cross section used as a primary standard for the rest of the library, the ^{235}U fission cross section, will be the values recommended by Battelle (RP512) in the energy range below 1.0 eV.

A considerably expanded set of heavy actinide cross sections being prepared for this library is benefiting directly from the 25 new or revised nuclide evaluations produced for ENDF/B-V by Savannah River Laboratory (RP451). *Program Manager: Odelli Ozer*

At the Institute

BOARD APPROVES $42 MILLION IN NEW RESEARCH

Some of EPRI's management staff and other officials meet at an August 12 Board of Directors meeting in Denver, where approvals were given for 57 new projects and authorizations were increased for 18 active projects. Discussing the new research are (left to right) J. Bonner, president and chief operating officer, Pacific Gas and Electric Company; Thomas Ayers, chairman and president, Commonwealth Edison Company; R. L. Rudman, director of planning, EPRI; Chauncey Starr, president of EPRI; Shearon Harris, president and chairman of the board, Carolina Power & Light Company; J. E. Watson, manager of power, Tennessee Valley Authority; and L. F. Lischer, vice president, engineering research and technical activities, Commonwealth Edison Company.

At its meeting in Denver on August 13 the EPRI Board of Directors authorized $42 million in electric energy research for 57 new projects and increased authorizations for 18 active projects.

The Board approved several related projects to reduce the amount of water consumed by a steam power plant and to reduce the heat and chemicals eventually discharged into water. In order to meet stricter environmental standards, electric utilities need the improved water management systems that EPRI is now authorized to develop.

Approval was also given for the design of a pilot plant to test a process for manufacturing a relatively inexpensive and clean synthetic distillate fuel from coal. The fuel would be used primarily in utility gas turbines.

EPRI was authorized by the Board to lease from Westinghouse Electric Corp. the Underground Cable Test Facility located at Waltz Mill, Pennsylvania, for a 10-year period and to assume operating responsibility. Supported by the electric utility industry since 1967, the facility has been owned and operated by Westinghouse. Under EPRI operation, it will continue to be used as a proving ground for new types of cables.

Approval was also given for research on a gas-insulated, vapor-cooled transformer that would be less expensive and more reliable than conventional transformers. Another key project will explore whether transformer energy losses can be reduced by using amorphous metallic alloys as components.

The federal government and the utility industry have recently indicated increased interest in continuing to examine the commercial potential of gas-cooled nuclear power reactors that can be run at very high temperatures. Extensive research has already been carried on by the government, the utility industry, and General Atomic Co. of San Diego. As a result of the August Board action, EPRI will review the commercial potential of the steam cycle of the high-temperature, gas-cooled reactor, as well as the technical obstacles that may need to be resolved.

Other approvals include projects for evaluating the availability of raw materials needed to begin the large-scale introduction of energy storage battery systems; researching the implications of domestic oil and gas supplies on electricity demand; forecasting the growth of industrial self-generated electricity, especially in the paper, chemical, and primary metals industries; and developing screening techniques for identifying the viability of budding technologies.

USSR and EPRI Discuss Joint Research

At a recent meeting with representatives from the Kurchatov Institute of Moscow, F. Robert Scott (standing) briefly describes EPRI's projects on fusion-fission energy systems to (left to right) Guelly Ye. Shatalov, Kurchatov Institute; Vladimir I. Pistunovich, Kurchatov Institute; K. Makowski, an interpreter; and V. G. Vasiliev, Iworg National Institute of Moscow.

Representatives from the USSR Kurchatov Institute met with EPRI staff in Palo Alto on July 19 and 20 to discuss the possibility of a cooperative research program in fusion-fission energy systems. William Gough, manager of EPRI's Fusion Program, reports that this was a continuation of earlier discussions held in both the U.S. and the USSR.

"The July meetings continued progress toward reaching an initial agreement that would establish a joint working group in charge of preparing the overall plan," Gough said. The July meeting followed a U.S.–USSR symposium at the University of California, Lawrence Livermore Laboratory, where the major work of both countries on fusion-fission reactors was presented.

The EPRI–USSR program would test modules to demonstrate fission fuel breeding and fission waste transmutation on the Soviet T-20 tokamak fusion machine. The T-20, which is scheduled for full operation by 1983, is uniquely suited for fusion-fission experiments because of its massive size and neutron fluences. No other machine with these characteristics is planned to be operating anywhere in the world in the same time period.

Using a fusion-fission system to produce fuel for nuclear fission reactors and to dispose of nuclear fission wastes is conceptually promising, but according to Gough, "requires more realistic engineering evaluation to assess its technical problems and economic potential."

Should a joint program be established with the Soviets, the modules would be designed and built in the U.S., installed and tested by a joint team in the Soviet Union, and returned to the U.S. for destructive testing.

Critical Flow Experiments

Discussing the possibility of EPRI's participation in critical flow tests planned at the Marviken Test Station in Sweden are (left to right) K. A. Nilsson, EPRI; Ragnar Nilson, AB Atomenergi; Stig O. W. Bergström, AB Atomenergi; Hans-Göran Thorén, AB Atomenergi; W. B. Loewenstein, EPRI.

The possible participation of EPRI in critical flow tests being planned at the Marviken Test Station in Sweden for late 1977 was the topic of a July 19 meeting in Palo Alto.

According to K. A. Nilsson, "The Marviken critical flow tests may ultimately involve the U.S., France, Japan, Holland, and the Nordic countries." Nilsson, a project manager in the Nuclear Power Division, Safety and Analysis Department, explains that Marviken is unlike any other test station because of its large blowdown capability.

"Researchers will thus be able to closely study two-phase critical flow in large-diameter pipes, simulating the hypothetical loss-of-coolant accident conditions postulated for a nuclear power plant," Nilsson stated. Critical flow, which is the maximum mass flow possible through an open-ended pipe under specific thermal-hydraulic conditions, is an important parameter for reactor safety assessment.

Fabric Filter Workshop

Fabric filters for fly ash collection from coal-fired utility boilers were the subject of a July 13 workshop sponsored by EPRI and attended by utility representatives. Discussion topics included regulatory issues, fabric filter design and specifications, the potential for dry SO_2 removal, and the results of recent field tests supported by EPRI.

Robert Carr, project manager for air quality control, states that the recent utility interest in fabric filters can be traced to technological problems with electrostatic precipitators. These problems are partially due to stricter environmental regulations for particulate emissions; a shift to low-sulfur, western coal to comply with sulfur-dioxide standards; and current coal delivery practices that result in wide variations in coal properties.

At the Denver meeting, participants reviewed results of an EPRI field test on the fabric filter at the Colorado-Ute Electrical Association Nucla Station. The Nucla project results showed that compliance with existing particulate standards is easily achieved, opacity is less than 1%, and the fabric filter is a very efficient collector of submicrometer particulates.

In addition to the Nucla study, operating experiences at the Sunbury and Holtwood stations of Pennsylvania Power & Light Co. were discussed. According to Carr, all three stations are relatively small and atypical utility boiler installations, unlike many of the plants that now have fabric filters on order. Accordingly, further test work on the new utility installations is probable when the units are brought on line.

Carr also reports that recommendations were made for more research on fabric filters, including the acquisition of quantitative data from other industries. These data, combined with data from a fabric filter test module investigation planned at the Arapahoe Station of Public Service Company of Colorado, will result in a more complete understanding of fabric filtration and provide utilities with appropriate design criteria.

The Arapahoe Station is the site of the planned EPRI test center for advanced flue gas cleaning processes.

Recent Workshop on New Conservation Program

The need to develop technology for increased conservation and efficient use of electric energy is a concern of the utility industry, and this has been recognized by EPRI through a new program in the Fossil Fuel and Advanced Systems (FFAS) Division. A five-day workshop was held in San Diego July 26–30 to aid EPRI staff in planning the new program on energy utilization and conservation technology.

The workshop brought together EPRI staff and utility representatives involved in energy management and conservation programs, as well as other experts in areas of energy conservation.

"The workshop generated a good overview of research, development, and demonstration areas relevant to EPRI programs, provided insight into industry concerns about energy conservation, and established an excellent basis for working with our utility advisers," commented Fritz Kalhammer, director of the Energy Management and Utilization Technology Department, which is one of four departments created by a recent reorganization of the FFAS Division.

"The workshop was an important first step toward establishing a five-year research and development program responsive to the utility industry's needs and consistent with EPRI's broad mission and specific programs," Kalhammer stated.

This workshop was similar to those held when the solar, geothermal, and other EPRI programs were in the planning stages.

Name Change for Two Divisions

The titles of two EPRI divisions were recently changed to better reflect their responsibilities. The Electrical Systems Division is the new title for the Transmission and Distribution Division, and the Energy Analysis and Environment Division is the new title for the Energy Systems, Environment, and Conservation Division.

The field of work in the Electrical Systems Division extends from the turbine-generator coupling to the customer's meter, including transformers and substations. The new name will more accurately reflect that broad scope.

The Energy Analysis and Environment Division examines the potential energy demand and economic effects of conservation. Its new name better describes the primarily analytic nature of this division's efforts since work on conservation technology is the responsibility of the Fossil Fuel and Advanced Systems Division.

Project Highlights

First-Generation Fuel Cells

A $42 million demonstration project that could lead to the introduction of commercial fuel cell power plants within 10 years was announced recently.

Demonstration of a 4.8-MW electric power plant on a utility system will be funded and managed by ERDA, EPRI, and United Technologies Corp., manufacturer of the equipment. The project will be in two phases: construction and testing.

The contract for the construction of the demonstrator, which will take two years, has been executed. The installation and testing by a host utility will take approximately one year. This final effort will result in a fully certified module of the first-generation fuel cell power plant, which will help expedite the introduction of larger plants by the early 1980s. According to Arnold Fickett, manager of EPRI's fuel cell project, the first commercial units will have a capacity of about 27 MW—enough electricity for a community of about 10,000.

The fuel cell is a sandwichlike device: two electrodes with an electrolyte in between that performs the same function as the acid in an automobile battery. A fuel is fed to one electrode and air to the other. The resultant electrochemical reaction produces power without noise or moving parts, with water as a by-product.

"Since electric power is produced without combustion, pollution emissions are well below the most stringent standards. This, coupled with its quiet, water-conserving operation, means the fuel cell is very acceptable from an environmental point of view," Fickett said. Further, because fuel cells are not limited by the Carnot cycle, they offer the potential for much higher energy efficiencies than conventional generators.

The modular design is another attractive feature mentioned by Fickett. This allows a utility to install "exactly as much capacity as needed, while providing quick delivery and the option to site the generators where needed. And unlike other generators, their size is not related to efficiency: smaller units operate just as efficiently as larger ones."

Although relatively unknown to the public, especially as a potential source of electricity for homes and businesses, the fuel cell concept has been around since 1839 when Sir William Grove first demonstrated the principle in England. But it was not until the space program that the idea was put to useful work. Environmental concerns, coupled with the energy crisis, have provided the impetus for researchers to show that commercial fuel cell development would permit utilities to get more power from less fuel.

The construction and testing of the demonstrator marks the first major role by EPRI and ERDA in first-generation fuel cell development. The Power Systems Division of United Technologies has been conducting research on electric utility fuel cells since 1972 in a joint program with nine utilities: Southern California Edison Co.; Public Service Electric and Gas Company of New Jersey; Consolidated Edison Company of New York, Inc.; Northeast Utilities; Niagara Mohawk Power Corporation of Syracuse, New York; Philadelphia Electric Co.; Boston Edison Co.; New England Electric System; and Consumers Power Company of Michigan.

Wind As a Power Source

The potential for harnessing the power of the wind as a source of usable energy is being assessed in a year-long study sponsored by EPRI.

Under a recently awarded $199,000 contract, General Electric Co. is evaluating the requirements for integrating wind energy systems (WES) with the generating facilities of the nation's electric utilities. This is the first study funded by EPRI that focuses solely on WES and how they might be used by utilities. Other EPRI studies are assessing the environmental impact of various types of solar energy, with wind energy conversion as one of the options.

"In this particular study we are looking for the preferred utility application of wind energy conversion," stated Piet Bos, manager of EPRI's Solar Energy Program. "We want to see whether wind energy systems would be better suited to small, rural utilities or to larger ones; whether they might be used to provide electric power to augment a small diesel engine, for example, or whether they might be better employed in providing mechanical power for irrigation purposes."

Bos stressed that the study would be assessing wind energy systems "from the technical, economical, and environmental points of view" and would be looking at all possible methods for converting wind to a usable energy source. These include the horizontal axis wind machine, such as the Dutch windmill, and the vertical axis machine. "We're always on the lookout for innovative approaches," he noted.

Wind energy would be an erratic source of power, Bos explained, because of its intermittent and unpredictable nature. Therefore, any method of using it would require expensive energy storage devices or widespread geographic dispersion and interconnections to achieve capacity displacement. This may put WES at an economic disadvantage when competing in the marketplace.

EPRI's program in wind energy conversion is designed to be complementary to wind energy programs being conducted by ERDA.

Conventional Mining Techniques Still Dominant

The projected increase in underground coal production will come largely from existing mining technologies, with new techniques beginning to make an impact by the late 1980s, according to a study recently concluded. The EPRI study was limited to underground coal mining and complements work sponsored by the U.S. Bureau of Mines on surface coal mining.

The study report, *Underground Coal Mining: An Assessment of Technology* (EPRI AF-219), states that "reliance must be placed on existing equipment and procedures if projected increases in production are to be realized in the near term."

Richard Schmidt, EPRI project manager for fuel resource assessment, explains that these findings on underground coal development methods facilitate preparation of plans and programs for future production, worker training, and equipment manufacturing.

The report analyzes costs and productivity for the two most frequently used underground mining techniques: conventional and continuous. "Conventional mining techniques, using separate, highly specialized pieces of equipment, were shown to be cheaper and more productive in several cases than the single machine, continuous method," Schmidt says. "One reason is that the operation time of a continuous miner is limited to comply with standards for health and safety of the mine workers."

The report emphasizes that although conventional units are generally more reliable and more available than continuous systems, they require better planning and coordination to avoid production-limiting bottlenecks. The adoption of new underground mining methods is expected to be slow, however, because of the high cost of the new machinery. According to the report, there is no incentive for a switch as long as operators continue to use existing units and to replace or repair them. Instead, there is every incentive to continue present manufacturing patterns because of this steady and secure market.

Yet another reason for slow substitution in mining equipment is the conservative approach of operators and miners to innovation. Examined fully, these fears are quite rational. Because of the inherently high risks in capital, health, and safety, operators and miners like to have proof of performance for a new machine. In coal mining, there is no competitive edge that results from being first.

In addition to comparing underground mining technologies, the report discusses the potential impact of a rapid increase in mining activity on a community, the environmental problems associated with mining operations, and recommendations for research and development.

One recommendation is to develop a technology for mining the thick underground coal seams found in the Rocky Mountain states. No techniques have been perfected for mining these seams, which can be from 30 to 100 feet thick, compared with coal seams in the Appalachian Mountains that measure 4 to 7 feet.

Throughout the project, the contractors—Hittman Associates, Inc., Pennsylvania State University, and George Washington University—worked closely with a committee of representatives from government, universities, utilities, coal-producing companies, and environmental organizations so that a cross section of many viewpoints was considered in the report.

"Since more than two-thirds of our nation's coal reserves are recoverable only by underground mining methods," Schmidt remarks, "there's no question but that all available underground coal recovery methods must be applied if we are to obtain the necessary supplies of fuel."

EPRI Negotiates 30 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Mgr.
Fossil Fuel and Advanced Systems Division				
RP532-2	Electrostatic Precipitator Plate Rapping and Reliability	19 months	71.0	Cottrell Environmental Sciences *O. Tassicker*
RP549-2	Individual Load Center–Solar Heating and Cooling (ILC-SHAC) Residential Project	11 months	220.0	Arthur D. Little, Inc. *J. Cummings*
RP716-2	Corrosion Chemistry in Low-Oxygen Activity Atmospheres	2 years	23.0	Ohio State University Research Foundation *R. Jaffee*
RP721-1	Criteria for the Selection of SO_2 Sorbents	1 year	82.6	Westinghouse Electric Corp. *M. Maaghoul*
RP722-1	Preliminary Design and Cost Estimate for a Commercial-Scale Atmospheric Fluidized-Bed Combustion (AFBC) Steam Generator	4 months	34.9	Combustion Processes, Inc. *S. Ehrlich*
RP725-7	Advanced Particulate Control Facility	1 month	50.0	Flow Research, Inc. *O. Tassicker*
RP779-6	Exploratory Bench-Scale Liquefaction Experiments	6 months	93.2	Hydrocarbon Research, Inc. *N. Stewart*
RP779-8	Autoadhesion Studies on SRC	7 months	19.8	Stanford Research Institute *W. Rovesti*
RP831-1	Application of Polymer Processing Technology to SRC Filtration	7 months	43.9	Fabric Research Laboratories *H. Lebowitz*
RP833-1	Chemical Removal of Pyritic and Organic Sulfur From Coal	6 months	200.0	Atlantic Richfield Co. *T. Lund*
RP842-1	4.8-MW FCG-1 Fuel Cell Power Plant Demonstration	2 years	5031.5	United Technologies Corp. *A. Fickett*
Nuclear Power Division				
RP510-1	EPRI/GE Cooperative Program on BWR Fuel Performance Evaluation	62 months	1057.6	General Electric Co. *F. Gelhaus*
RP617-1	Outgassing of UO_2 Fuel Pellets	17 months	43.4	University of California at Berkeley *H. Ocken*
RP623-1	Steam Generator Model Boiler Program	42 months	849.8	Combustion Engineering, Inc. *L. Martel*
RP768-1	Methodology Development for the Statistical Evaluation of Safety-Related Engineering Analysis	2 years	200.0	Westinghouse Electric Corp. *R. Gay*
RP812-1	Analysis of Fluid-Structure Interaction in BWR Pressure Suppression System	3 months	33.8	Science Applications, Inc. *J. Carey*
RP812-2	Fluid Structure Impact Analysis	4 months	28.4	Lockheed Missiles & Space Co., Inc. *J. Carey*
RP815-1	Hybrid Analytical Techniques for Transient Two-Phase Thermal Hydraulics	2 years	53.7	Waterloo Research Institute *L. Agee*
RP817-1	Water Impact Tests of BWR Pressure Suppression System Models	5 months	98.1	Developmental Sciences, Inc. *G. Sliter*
RP823-1	Development of an X-ray Device for Stress Measurement	11 months	100.0	University of Denver *G. Dau* *K. Stahlkopf*
RP828-1	On-Line Low Concentration Chemical Decontamination	35 months	1179.0	Battelle, Pacific Northwest Laboratories *D. Uhl*
RP829-1	Determination and Microscopic Study of Incipient Defects in Irradiated Power Reactor Fuel Rods	19 months	459.9	Battelle, Columbus Laboratories *A. Roberts*
RP829-2	Determination and Microscopic Study of Incipient Defects in Irradiated Power Reactor Fuel Rods	19 months	120.7	Westinghouse Electric Corp. *A. Roberts*
Energy Analysis and Environment Division				
RP803-1	U_3O_8 Production Cost Analysis: Task I, Sandstone Deposit Mine Model; Task II, Sandstone Deposit Milling Model	1 year	189.2	Bechtel Corp. *T. Browne*
RP803-2	Analysis of U_3O_8 Production Costs by Solution Mining	1 year	44.7	NUC Corp. *R. Urbanek*
RP853-1	Classification of Cooling Bodies of Water	5 months	148.4	Analytic Sciences Corp. *R. Goldstein*
RP859-1	Fossil Fuel Pollutants: Collation of Experimental and Clinical Information	11 months	126.8	Science Applications, Inc. *R. Kawaranti*
RP861-1	Oxidant Measurement in Western Power Plant Plumes	8 months	93.0	Meteorology Research, Inc. *C. Hakkarinen*
RP874-1	Bechtel and Brookhaven Models as Possible Tools for Environmental Impact Analysis	1 year	48.6	Pennsylvania State University *R. Michelson*
RP878-1	Methodology for Assessing Interpreted Effects of Multiple Power Stations on a Single Body of Water	47 months	478.4	Tetra Tech, Inc. *R. Goldstein*

Each month the JOURNAL publishes summaries of EPRI's most recent reports. Supporting member utilities receive copies of reports in program areas of their designated choice. Supporting member utilities may order additional copies from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303. Reports are publicly available from the National Technical Information Service, P.O. Box 1553, Springfield, VA 22151.

New Publications

Energy Analysis and Environment

EPRI ES-137 AIR QUALITY MODELS: REQUIRED DATA CHARACTERIZATION
Final Report

This report presents the results of a survey of data input requirements and output formats for current air quality plume models. Data requirements sufficient for the majority of the 45 models surveyed are presented, covering recommended measurements for siting, wind field, dispersion, source emissions, and chemistry components of the models. Various methods of generating wind fields and computing dispersion input parameters are described. The report concludes with an assessment of critical deficiencies in the present state of air quality data for modeling purposes and outlines possible remedies. *Science Applications, Inc.*

EPRI EC-184 DETERMINATION AND POSSIBLE PUBLIC HEALTH IMPACT OF TRANSITION METAL SULFITE AEROSOL SPECIES
Topical Report

The levels of sulfur compounds in polluted air, their possible harmful effects, and their control are of great practical concern. This preliminary report presents evidence for the existence of metal sulfites in the air of the Salt Lake Basin. It points out that such compounds could be more responsible for adverse health effects than are other sulfur compounds such as sulfates, which are usually blamed, or sulfur dioxide, which is now used as an indicator pollutant for health effects and regulatory action. This could have considerable bearing on the setting of air pollution standards and the type of control equipment or systems that are needed for effective reduction of adverse health effects. The findings must be viewed with considerable caution as far as practical applications are concerned, but they do demonstrate that control of fossil fuel combustion products is very complex and that further understanding is needed of chemical conversions and transport in the atmosphere in order to deal effectively with air pollution. *Greenfield, Attaway & Tyler, Inc.*

Fossil Fuel and Advanced Systems

EPRI ER-171 A FEASIBILITY STUDY OF A LINEAR LASER–HEATED SOLENOID FUSION REACTOR
Final Report

This study is an assessment of the laser-heated solenoid reactor concept in terms of its plasma physics, engineering design, and commercial feasibility. Within the study many pertinent reactor aspects were treated, including: physics of the laser-plasma interaction; thermonuclear behavior of a slender plasma column; end-losses under reactor conditions, design of a modular first wall, a hybrid (both superconducting and normal) magnet, a large CO_2 laser system, reactor blanket, electrical storage elements; neutronics; radiation damage; and tritium processing. Self-consistent reactor configurations were developed for both pure fusion and fusion-fission designs, with the latter designed both to produce power and/or fissile fuels for conventional fission reactors. *Mathematical Sciences Northwest, Inc.*

EPRI EM-181 PREPARATION AND PROPERTIES OF BETA–ALUMINA—GLASS COMPOSITES
Final Report

A key to the success of the high-temperature sodium battery systems is the development of a suitable solid electrolyte. Both glass and beta-alumina ceramic have been shown by many developers to be technically viable in small laboratory cells. An attempt was made in this project to fabricate a material having the most desirable features of the glass and ceramic materials. Hot-pressed composites of the two were explored in order to achieve an inexpensive material having the fabricability of glass while providing the conductivity of the ceramic. However, three of the four glasses used reacted with the beta-alumina during fabrication and two of the three reacting glasses formed nonconductive barriers between the beta-alumina crystals. In the case where no reaction occurred between the components of the composite, poor contact between beta-alumina crystals caused high resistivity. In all cases, materials that were both conductive and fully dense could not be fabricated. Since glass selection is limited due to the degradation of most glasses by sodium, chances for ultimate success of this approach are remote. *University of California at Los Angeles*

EPRI AF-182 UNDERGROUND PUMPED STORAGE RESEARCH PRIORITIES
Technical Planning Study

This project examines the current status of underground pumped storage to identify specific elements requiring developmental work. Aspects reviewed include siting and site investigation, provision of access to the underground facilities, excavation of the lower reservoir cavern, and availability of rotating equipment. Primary areas recommended for developmental work include the adaptation of mining technology to the lower cavern excavation, the development of hoist equipment capable of handling loads to 120 tons, and the extension of single-stage reversible pump turbine capability to the 2460–3280-ft (750–1000-m) head range. *Acres American Incorporated*

EPRI ER-188 ASSESSMENT OF CADMIUM SULFIDE PHOTOVOLTAIC ARRAYS FOR LARGE–SCALE ELECTRIC UTILITY APPLICATIONS
Final Report

At the present time, economic constraints dictate that the photovoltaic devices most likely to achieve viability for large-scale applications are those that can be produced in thin-film form. The most developed thin-film solar cells are copper sulfide/cadmium sulfide heterojunction devices. Recent results strongly suggest that these devices can be stable for long periods, but their large-scale utilization will require conclusive verification of both cell stability and process reproducibility.

A procedure is described that yields nominal cost and performance objectives for any solar cell material employed in nonconcentrating photovoltaic central stations with horizontal arrays, as functions of power plant capital cost and structure and wiring costs. Results obtained imply that economically competitive utility central station applications will probably require cell conversion efficiencies of 12% or greater and cell costs of approximately $1/ft². Recent results with Cu_2S/CdS cells suggest that these objectives may be achievable, with the higher efficiencies probably the more difficult to attain. The analysis shows that the structure and wiring costs are likely to be of the same order of magnitude as cell costs in competitive power plants, suggesting a possible relaxation of the above solar cell objectives if low-cost structure and wiring schemes can be developed. *Brown University*

EPRI AF-190 CATALYST DEVELOPMENT FOR COAL LIQUEFACTION
Annual Report

This report covers the first year of a three-year contract that has as its objective the development of one or more superior heterogeneous catalysts for the direct liquefaction of coal. These catalysts would find application in the production of clean boiler and turbine fuels in processes now under development, such as H-Coal and Synthoil. Improved catalysts are sought to lower fuel costs by allowing operation at lower severity and by lowering hydrogen consumption while achieving the required product quality.

An extensive literature search was completed and the results used to guide the early stages of the project. Both batch and continuous-flow reactor units were constructed to provide information on initial catalyst activity and activity maintenance, respectively. From the results obtained in these units, two or three catalysts will be selected for long-term aging tests, and subsequently, a large batch of the best formulation will be produced by a commercial catalyst supplier.

After the effects of operating parameters were determined to establish suitable conditions for screening tests in the batch unit, initial performance data were obtained on over 60 cobalt-molybdenum catalysts, both available commercially and supported on a variety of refractory oxides. Alumina was found to be the best support, with its performance in a given formulation related to its surface and structural properties. Several commercial and laboratory-prepared catalysts were identified as having superior initial activities for Illinois No. 6 bituminous coal conversion and desulfurization. Denitrogenation activities thus far have shown no improvement. Delays in the receipt of key components had not allowed for completion of the continuous-flow unit during the period covered by this report. *Amoco Oil Co.*

EPRI AF-219 UNDERGROUND COAL MINING: AN ASSESSMENT OF TECHNOLOGY
Final Report

Coal represents a major source of energy to the electric utility industry. While important coal reserves can be recovered through strip-mining methods, the bulk of the nation's coal deposits occur deep beneath the surface where underground mining techniques are required. A better understanding of the opportunities and constraints inherent in underground coal mining is needed to place in perspective its potential for meeting future requirements.

In an attempt to compile and evaluate the present state of underground coal mining as a guide to anticipated future developments, EPRI sponsored a multidisciplinary study. Among the topics covered are (a) roles and interests of participants in underground coal mining and affected parties, (b) underground coal mining technology today, (c) systems analysis of interrelationships, and (d) new coal mining technology to the year 2000. *Hittman Associates, Inc.*

EPRI 1235-2a LABORATORY ANALYSIS OF SOLVENT–REFINED COAL
Technical Report 1

EPRI 1235-2b SOLVENT–REFINED COAL EVALUATION: PULVERIZATION, STORAGE, AND COMBUSTION
Technical Report 2

The 1235 series of reports documents the results of the investigation of the storage, handling, and combustion characteristics of solvent-refined coal (SRC). Such information would permit boiler manufacturers to design new units for burning SRC and to determine retrofit requirements (if any) for existing units burning coal.

The SRC reports summarize activity for a wide range of tasks. Initial work included bench-scale analyses of SRC, such as fuel analysis, pulverizing, and transport. The culmination of the effort was a 2-t/hr ball-and-race pulverizing and direct-firing test to simulate as closely as possible operating conditions in a utility plant using conventional equipment. *Combustion Engineering, Inc.*

Nuclear Power

EPRI NP-155 SURVEY OF RADIATION PROTECTION, RADIATION TRANSPORT, AND SHIELDING INFORMATION NEEDS OF THE NUCLEAR POWER INDUSTRY
Final Report

This report on the radiation protection, radiation transport, and shielding information needs of the nuclear power industry was constructed from the response to a questionnaire, from RSIC records of communications and code package transmittals and requests, and from published information. The RSIC effort was intended to cover the public and private utilities, the architectural-engineering and other consulting firms, and the reactor vendors. The report details the self-perceived needs of the industry in the following areas: computer technology; data needs; suggested RSIC operations, projects, and services; computer code and data base requirements; and industry needs in the area of fission product and "crud" transport. *Oak Ridge National Laboratory*

EPRI NP-176 "STEALTH," A LAGRANGE EXPLICIT FINITE–DIFFERENCE CODE FOR SOLIDS, STRUCTURAL, AND THERMOHYDRAULIC ANALYSIS
Technical Report 1

A useful computer simulation method based on the explicit finite-difference technique can be used to address transient dynamic situations associated with nuclear reactor design and analysis.

This report contains an introduction to explicit finite-difference technology, the theoretical background (physical and numerical), a review of some explicit codes, a discussion of nuclear reactor applications, and a brief description of EPRI's STEALTH codes. STEALTH computer code manuals are available that describe the numerical equations, programming architecture, input conventions, sample and verification problems, and plotting system.

It is anticipated that STEALTH will be applicable in design situations such as water-hammer, soil-structure interaction, missile impact, mixed-phase fluid impact, and fluid-structure interaction. The first version to be released will be one- and two-dimensional with extensive plotting capabilities. Future developments will include extension to three dimensions and coupling with shell elements. *Science Applications, Inc.*

EPRI NP-180 ^{235}U FISSION PRODUCT DECAY HEAT FROM 1 TO 10^5 SECONDS
Final Report

This report describes the experimental measurements made on ^{235}U samples to determine the decay heat following thermal fission. The measurements were conducted at IRT Corp., using its "nuclear calorimeter," which is based on a large, 4000-liter, liquid scintillator detector. The ^{235}U irradiations were made in a water-moderated ^{252}Cf source with a rapid pneumatic system to transfer the sample to the scintillator device. Detailed information is given on the experimental apparatus and the procedures used.

The results for beta ray, gamma ray, and total decay heat are presented. The systematic uncertainty of the measurement is 2.4%, with statistical uncertainties of 2% at 1 second, increasing to 4% at 10^5 seconds. The results of the experiments are compared with calculations and the current standard ANS 5.1 *IRT Corp.*

EPRI NP-194 METHODOLOGY DEVELOPMENT FOR STATISTICAL EVALUATION OF REACTOR SAFETY ANALYSIS
Final Report

In February 1975, Westinghouse Electric Corp., under contract to EPRI, started a one-year program to develop methodology for statistical evaluation of nuclear-safety-related engineering analyses. The objectives of the program were:

- To develop an understanding of the relative efficiencies of various computational methods, which can be used to compute probability distributions of output variables due to input parameter uncertainties in analyses of design basis events for nuclear reactors
- To develop methods of obtaining reasonably accurate estimates of these probability distributions at an economically feasible level

We decided at the outset that an investigation of the efficiency of various techniques should not initially be carried out on the realistic long-running codes. We preferred to take a gradual, systematic approach to evaluating the several techniques, first applying them to simple and short-running codes, then to those of increasing complexity and running times. The experience thus acquired will help evaluate their usefulness in long-running computer codes.

In our work, we have applied the different techniques to two relatively simple problems. The first case corresponds to a simple thermal-hydraulic problem whose output variable (peak cladding temperature) is given as a closed-form expression in the input variables. Subsequently, a similar investigation was carried out for a thermal-hydraulic problem, where the relationship between the predicted variable and the inputs is described by a short computer program.

The report details the methodologies investigated and the results achieved. *Westinghouse Electric Corp.*

EPRI NP-195 SINGLE–PHASE AND TWO–PHASE FLOW MEASUREMENT TECHNIQUES FOR REACTOR SAFETY STUDIES
Topical Report

This report is an assessment of the state of the art of measurement methods used in transient conditions of steam-water, or two-phase flow. The material is arranged to provide a relatively uniform evaluation of each of the applicable methods in current practice or in the literature. The evaluation attempts to test each method against factors of performance, environmental sensitivities, survival in hostile environments, and implementation. An extensive bibliography is included. One of the most important conclusions from this study is the necessity for a two-phase-flow facility, in which all important fluid state conditions can be generated, for evaluating and calibrating the promising techniques in a uniform and comprehensive manner. *Intermountain Technologies, Inc.*

EPRI NP-196 CLEAN CRITICAL EXPERIMENT BENCHMARKS FOR PLUTONIUM RECYCLE IN LWRS
Final Report, Volume I

Recycling of plutonium in thermal power reactors has significant conservation advantages. It reduces the requirements for uranium ore and for separative work at uranium enrichment plants. For these reasons, government laboratories and private industry in the U.S. and in other countries have carried out or initiated programs to study and evaluate the technical and economic feasibility of recycling plutonium. A thorough knowledge of the neutronic behavior of plutonium-fueled systems is fundamental to establishing valid technical bases for design and management of plutonium reloads.

The experimental measurements program provides benchmark neutronics data for use in assessing the accuracy of neutronics analysis methods for slightly enriched uranium lattices and for mixed oxide (UO_2-PuO_2) lattices.

A series of 12 lattice experiments were performed (a) to determine neutronics parameters, such as the number of fuel rods needed to achieve criticality when unborated or the boron concentration needed in the moderator to achieve criticality when borated, and (b) to measure the power distributions throughout the cores. The 12 experiments consisted of 6 lattices containing UO_2-2.35% ^{235}U fuel and 6 lattices containing UO_2-2 wt% PuO_2 (8% ^{240}Pu). The lattice pitches were selected to provide configurations that were undermoderated, near optimum moderation, or overmoderated and that had approximately the same water-to-fuel volume ratio for both fuel types in each degree of moderation. *Battelle, Pacific Northwest Laboratories*

Electrical Systems

EPRI TD-172 HIGH–VOLTAGE TRANSMISSION CONDUCTOR MOTION RESEARCH
Final Report

The first recognition of the problems caused by wake-induced oscillations of bundled conductor transmission lines was the result of hardware damage and failure. This recognition, which occurred about 1968, has been followed by various investigations into means of eliminating or inhibiting the oscillations.

This program, under the sponsorship of EPRI, EEI, and Alcoa, has been under way for three years. The purpose of the program was to develop the technology required for design of bundle conductor transmission lines and for alteration of existing lines to prevent the oscillations.

The investigation has encompassed a program of measurements of oscillation behavior of existing lines, measurements of turbulence of natural winds to which the lines are exposed, wind tunnel measurements of aerodynamic characteristics of conductors in bundles, and development of theoretical and computer analyses predicting conditions under which actual spans may oscillate. The computer analyses used with the wind tunnel data developed in the program provide a useful tool for predicting the effectiveness of devices and procedures intended to prevent oscillation. The influence of local terrain is taken into account.

Comparison of predictions based on the computer analyses with measured behavior of actual field spans is satisfactory in the cases where comparison was possible. The number of such cases is limited by the range of the wind tunnel data that must be used with the computer analyses. *Aluminum Company of America*

EPRI TD-193 STUDY OF CRITICAL CURRENTS OF VERY THIN MULTILAYERED STRUCTURES
Final Report

The Stanford program that has been carried out under joint ERDA-EPRI sponsorship has been directed at:

- Trying to enhance the maximum superconducting current density, J_c, that can be sustained in the superconductor Nb_3Sn through formation of fine-scale layered composites, and developing the procedures and processes for their fabrication by using electron beam evaporation. These composites consist of alternating layers of Nb_3Sn and normal metal, which serve as flux pinning barrier regions.

- Surveying the dielectric losses of potential low-temperature insulating materials in order to identify suitable candidates for actual power line use, and attempting to identify the physical origins of the observed losses.

Stanford has shown that layered composites can be made in a controlled manner. In addition, the fabrication technique allows the overall thickness of the conductor to be increased without degradation of the inherent superconducting properties, thus making possible single conductors with a total J_c in the fault level regime. The present layered conductors are susceptible to instabilities under fault level ac conditions, however. To date, no attempts have been made to stabilize these conductors.

Stanford dielectric studies have established the fact that the intrinsic dielectric loss of nonpolar polymers is smaller than the usual SPTL specification that $\tan \delta \lesssim 2 \times 10^{-5}$. They have found that the dielectric loss is strongly influenced by the additives present in commercial polymers. Stanford has identified commercial polymers containing specific additives with dielectric losses acceptable for SPTL applications. *Stanford University*

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