Fuel Cells for Urban Power

Also in this issue • *Zebra Mussels* • *Ground-Source Heat Pumps* • *Profile: John Sawhill*

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Cover: Clean, efficient, and compact, fuel cell power plants can be sited in dense urban areas, where space and environmental constraints are particularly stringent.

EDITORIAL

Fuel Cells: Fulfilling the Promise

The advantages of fuel cells for utility applications have long been recognized: they are exceptionally clean, efficient, small, and versatile. But they are also relatively expensive and, for a variety of reasons, have lagged in commercialization efforts aimed at widespread utility use in this country. Now a combination of technical, environmental, and economic factors is knocking down old barriers and bringing fuel cells to the threshold of fulfilling their still-bright promise as a competitive source of electric power.

First, the economics. Meeting demand growth in congested urban areas through expansion or addition of conventional power plants and transmission facilities is becoming more difficult. Therefore relatively small, dispersed generation units, which can be placed close to impacted load sites, hold an increasingly important economic advantage. Calculating the benefits of dispersed generation, represented by fuel cells and some renewable technologies, has thus become a major focus in the development of integrated resource planning models that look beyond busbar costs to include a whole spectrum of avoided costs and so-called economic externalities.

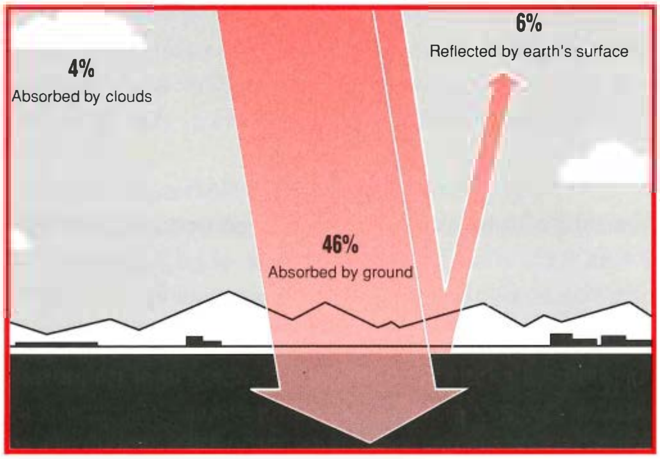
Probably the most important of these externalities—social costs not previously considered in planning and rate-setting discussions—relate to environmental protection. The 1990 amendments to the Clean Air Act provide a mechanism by which utilities can trade pollution allowances among various power plants, and several states are experimenting with additional ways to account for the previously external costs of environmental protection. Such practices immediately put a premium on the environmental benefits of fuel cells, which offer by far the most efficient, least polluting way to derive energy from fossil fuels.

A new technology—the molten carbonate fuel cell—has reached utility-scale demonstration just in time to take advantage of these economic and environmental developments. Like other fuel cells, the MCFC is small enough and clean enough for siting near load centers, even in the central city. But it also has some unique advantages, including even higher efficiency than the commercially more mature phosphoric acid fuel cell and a better match for future use in integrated coal gasification facilities.

EPRI is deeply involved in each of the major aspects—economic, environmental, and technical—of fuel cell development and commercialization. Through such efforts, fuel cells are now beginning to fulfill their promise as an attractive source of power for utilities around the nation.

Ed Gillis

Ed Gillis
Manager, Fuel Cells Program
Generation and Storage Division



DEPARTMENTS

EPRI JOURNAL

Volume 16, Number 6 September 1991

4 Fuel Cells

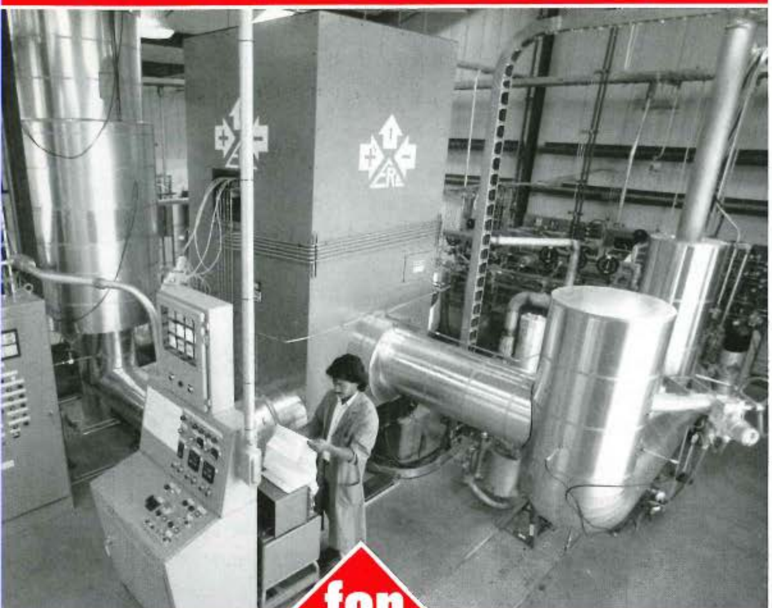
12 Zebra Mussels

THE STORY IN BRIEF

Producing electricity electrochemically—without combustion—fuel cells are ideal for serving power generation needs in urban settings. While units based on phosphoric acid technology are now operating successfully in Japan, the fuel cells most likely to be used in the United States are based on more advanced, molten carbonate designs, which offer higher efficiencies, greater compactness, and potentially lower cost. To speed the commercialization of fuel cells in this country, EPRI and the American Public Power Association sponsored an international competition in 1988 to design a fuel cell tailored to urban needs. The winner, a 2-MW molten carbonate fuel cell, will be produced under an innovative commercialization plan that will include completion of a demonstration plant by 1994, shared risks for early production units, and shared royalties on future sales for utilities that become involved in the early efforts.

A grid-connected, 100-kW molten carbonate fuel cell is undergoing tests at Pacific Gas and Electric's San Ramon research facility. This cell represents the basic building block from which 2-MW commercial plants will be built later in the decade.

FUEL CELLS



for

URBAN POWER

Supplying electric power to congested urban areas is like trying to solve a Chinese puzzle ball: multiple barriers have to be manipulated simultaneously, and the closer one gets to the center, the more complicated the whole process becomes. Consider the constraints facing today's municipal utility planner—increasingly tight emission controls, rising fuel costs, mounting resistance to expanding or upgrading transmission lines, lengthening construction times, shrinking land availability, and, in some cases, deteriorating system performance.

For more than two decades, the conceptually simple and environmentally attractive fuel cell has seemed to offer a technological solution to each of these problems. Compact, quiet, highly efficient, and exceptionally clean, fuel cell modules can be installed as needed on available urban sites, without the need to invest in large remote power plants and upgraded transmission lines. In addition, they respond well to load changes, can be used to correct power factor degradation in the urban grid, and offer considerable flexibility in the choice of fuel.

Spurred on by fuel cells' promise for small-scale urban applications, a group of utilities built and field-tested 12.5-kW fuel cell power plants in the early 1970s, and by 1977 a 1-MW pilot plant had been successfully demonstrated. Over the next decade, however, commercialization efforts ran into unexpected difficulties.

In 1988, the American Public Power Association (APPA) and EPRI decided to tackle the commercialization problem head-on. Alternative fuel cell technologies and developers had become available, and supply problems for municipal utilities—many of which are members of APPA—had grown more urgent. APPA issued a "Notice of Market Opportunity" (NOMO), which essentially offered volume sales for the winner of an international competition to design a commercialization program tailored to urban needs. EPRI helped choose the winning technology—a 2-MW molten carbonate design—and is now participating in its further development and demonstration.

Power without fire

Unlike conventional generation systems, fuel cells employ an electrochemical process—that is, they convert fuel energy to electricity through flameless oxidation. Skipping the combustion step makes the conversion process much more efficient than using a boiler to raise steam. It is also much cleaner: the main emissions from a fuel cell are water vapor and carbon dioxide.

As in a battery, an electric current is created by a fuel cell when chemical reactions release electrons at one electrode and absorb them at another. The difference is that the electrodes of a battery themselves provide the "fuel" and oxidizer and so are consumed by the chemical reactions. In a fuel cell, gaseous fuel (such as hydrogen, natural gas, coal gas, methanol, or naphtha) and oxygen (either from the air or purified) flow through porous electrodes, which are only slightly affected by the reactions.

Some of the technical challenges facing fuel cell developers are inherent. Each pair of electrodes can create an electric potential of only up to 1.23 volts, so many pairs are required for generating voltages useful for power-related applications. Current is proportional to the surface area of the electrodes, which means that large plates (about 1 meter square) with porous surfaces must be used. Expensive catalysts are required in low-temperature fuel cells to help accelerate the normally sluggish reactions, but these are not needed at high temperatures. And the electrolyte—the medium for carrying current inside a fuel cell—is a relatively poor conductor, so electrolyte-filled membranes separating electrodes are made as thin as possible.

Different kinds of fuel cells are usually named according to the type of electrolyte they use. Three major kinds are now being actively developed for utility applications: phosphoric acid fuel cells (PAFCs), the most highly developed, with major demonstration plants in operation; molten carbonate fuel cells (MCFCs), now entering the demonstration phase of development; and solid oxide fuel cells (SOFCs), which are still in the experimental stage.

Developing technology for the U.S. market

Phosphoric acid fuel cells, which operate at about 200°C with power generation efficiency of 35–45%, were first operated at utility scale at Tokyo Electric Power Company (TEPCO) in 1983. The world's largest fuel cell, an 11-MW PAFC, is currently operating at TEPCO, in addition to several smaller units (see sidebar).

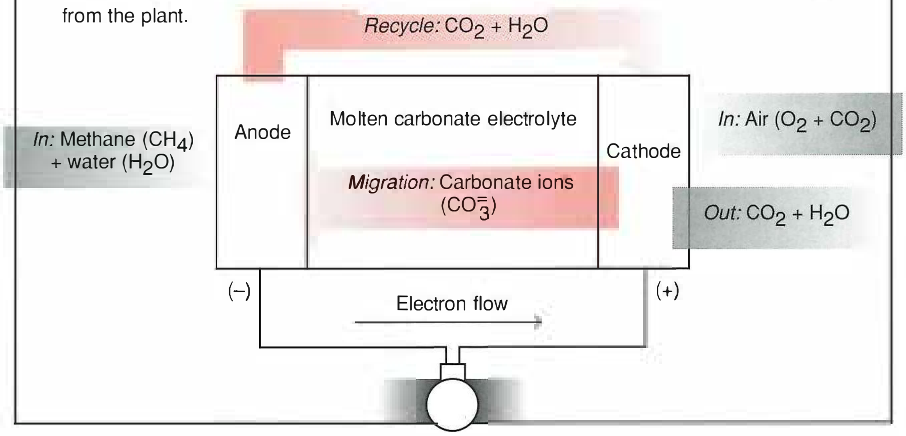
Europe is also pursuing the PAFC option, with a 1-MW PAFC demonstration plant scheduled to begin operation in Milan later this year. The project, sponsored by the Milan Municipal Energy Authority (Aem) and the Italian energy agency (ENEA), incorporates fuel cell stacks manufactured by International Fuel Cells Company (IFC) of the United States, which also produced the stacks used in the 11-MW TEPCO unit. EPRI has an information exchange agreement with Aem and is particularly interested in operational data about the performance and durability of an EPRI-developed fuel processor utilized in the project.

United States electric utilities, on the other hand, are not currently pursuing the PAFC option. "U.S. market conditions simply didn't favor a new technology when phosphoric acid fuel cells were first offered," says project manager Daniel Rastler, who has been monitoring the TEPCO efforts. "As a result, the Japanese certainly have an early lead in fuel cell commercialization. But as the U.S. rekindles its commercialization efforts, it will focus on leapfrogging the PAFC alternative and investing in the more advanced molten carbonate technology."

Although phosphoric acid cells are clearly ahead of other fuel cell technolo-

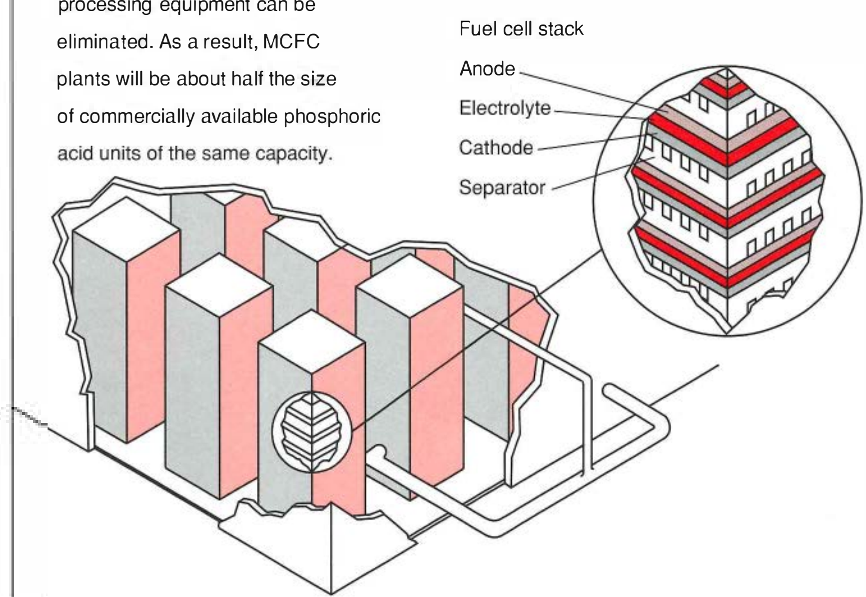
Electricity Without Combustion

At the MCFC's cathode, oxygen (O_2) and carbon dioxide (CO_2) react with available electrons to form carbonate ions ($CO_3^{=}$), which migrate through the molten carbonate electrolyte toward the anode. There the carbonate ions react with hydrogen and carbon monoxide, internally reformed from water and the methane fuel. Electrons released in the anode reactions produce a flow of electricity. CO_2 and water constitute the only emissions from the plant.



The MCFC Power Plant

The 2-MW MCFC power plant module will consist of 20 fuel cell stacks, each built up of many cell "sandwiches" of anode, electrolyte, and cathode. Because the high-temperature MCFC can reform the methane fuel to hydrogen inside the stack, bulky external fuel-processing equipment can be eliminated. As a result, MCFC plants will be about half the size of commercially available phosphoric acid units of the same capacity.



gies in being field-ready, they do have some disadvantages that the more advanced options don't. The most important is that PAFCs need an external fuel processor to enhance the hydrogen content of the fuel before it enters the cell. In a "reformer" section of this fuel processor, combustion is needed to heat a mixture of natural gas and steam, which react in the presence of a catalyst to form hydrogen and carbon monoxide. A "shift converter" section then reacts the carbon monoxide and steam to generate more hydrogen, also by using a catalyst. The need for a combustion-based fuel processor lowers the efficiency of a PAFC and increases its cost. Also, the reformer vessel is one of the largest components of a complete PAFC facility, requiring special handling and increasing the facility's "footprint"—the amount of floor space it occupies.

Because molten carbonate fuel cells operate at a high temperature—about 1200°F—reforming can take place inside the cell, without the need for any combustion to sustain the conversion reactions. Such internal reforming enables the MCFC to achieve exceptionally high efficiency with extremely low emissions. The absence of a separate reformer vessel also reduces the fuel cell's footprint. This simplicity of design is expected to make MCFCs more reliable and eventually less expensive than PAFC alternatives.

Because of these technical advantages and the commercialization strategy proposed, the NOMO reviewers chose a 2-MW MCFC designed by Energy Research Corporation (ERC) of Danbury, Connecticut, for support under the APPA/EPRI commercialization initiative. Although not as fully developed as PAFC technology, MCFCs have recently achieved some key technical milestones. Full-area cells (about 4 square feet) and tall stacks (with 60 cells each) have been successfully demonstrated. The next step is verification and durability testing of the first fully integrated 100-kW MCFC system. Such tests began in June 1991 at the Research Center of Pacific Gas and Electric Company (PG&E), in San Ramon, California.

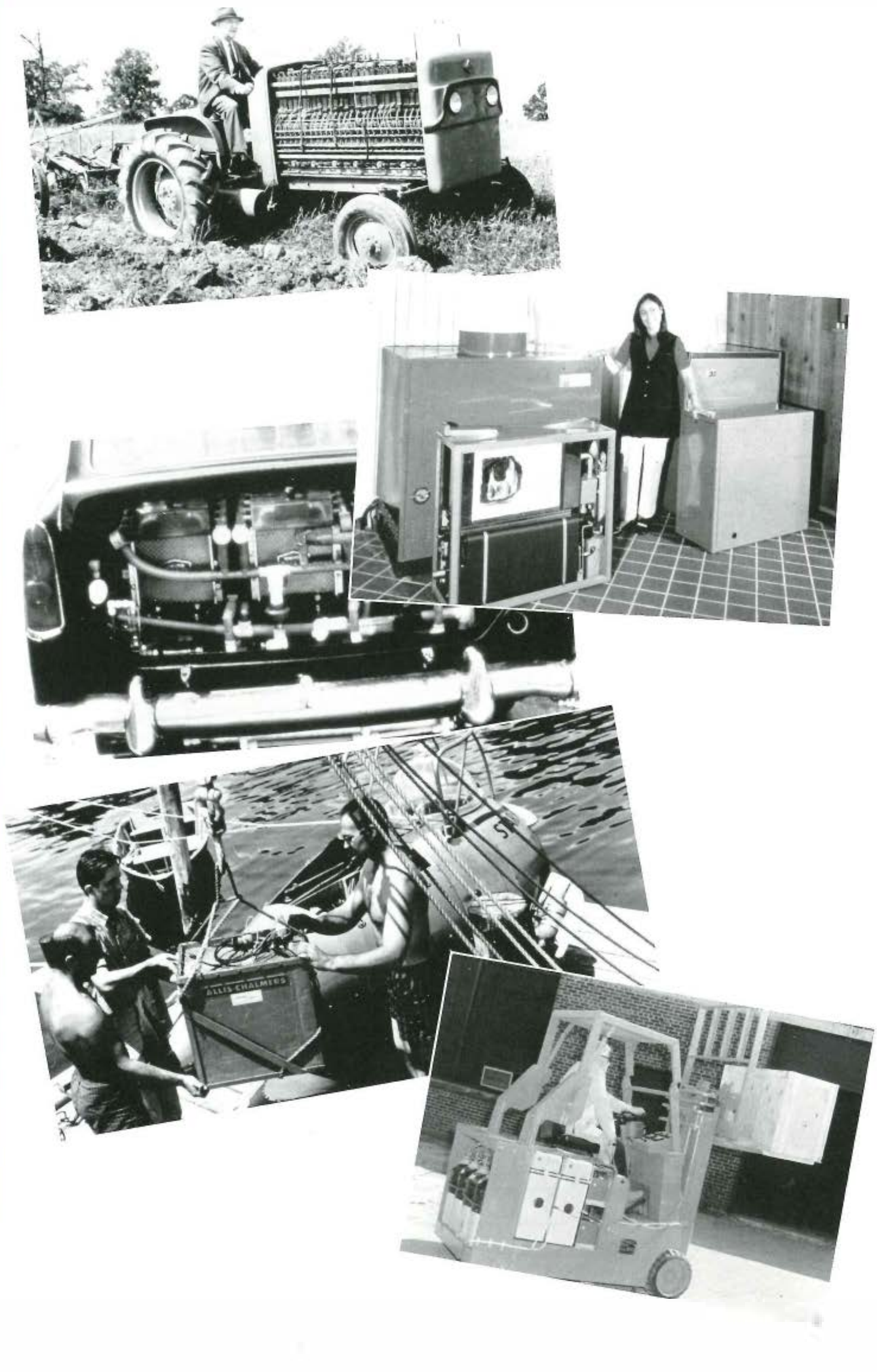
The MCFC design chosen for commercial demonstration will have a fuel-to-electricity energy conversion efficiency of 54–60% (5700–6300 Btu/kWh). With a footprint of less than 4500 square feet, the fuel cell would easily fit within the area of a tennis court, making it ideal for urban service areas. The nominal 2-MW plant can also operate over a wide power range—from about 25% to 125% of rating—depending on utility load requirements. This type of advanced fuel cell has been under development by ERC for the past 10 years, with support from the U.S. Department of Energy, EPRI, and PG&E. Negotiations for siting the first 2-MW demonstration unit are under way with the city of Santa Clara, California, and a consortium of other utilities.

Because both phosphoric acid and molten carbonate are highly corrosive, a particular challenge in developing these fuel cells has been to find materials that can withstand prolonged exposure to these chemicals. A solid oxide fuel cell avoids this problem by using a zirconium oxide ceramic material as the electrolyte. Such solid-state construction promises to make SOFCs exceptionally compact and lightweight—offering even more flexibility in size and siting. In addition, with an operating temperature of around 1800°F, SOFCs could produce higher-temperature steam than MCFCs and thus provide useful heat for a wider variety of cogeneration applications. The SOFC design can also produce concentrated carbon dioxide, which could—in principle—be captured and sequestered, should concern over the greenhouse effect become a dominant consideration.

SOFCs are expected to have a lower efficiency, however, and thus the technology will probably find use first as a topping cycle for an expansion turbine, replacing the combustion stage of a conventional gas turbine. The technology is

The Search for Early Applications

Attempts to commercialize fuel cells at sub-utility scale go back several decades, with most ideas centering on transportation. The tractor, forklift, one-man submarine, and automobile shown here date from the late 1950s and early 1960s and were powered by alkaline fuel cells—the type later used on the space shuttle. The home generator, developed in the late 1960s, never hit the market, but its phosphoric acid fuel cell technology was later scaled up for utility use.



Utility Fuel Cells in Japan

The first fuel cell to enter commercial-scale utility operation was a 4.5-MW unit that went on-line at the Goi thermal power station of Tokyo Electric Power Company (TEPCO) in 1983 and generated power until 1985. This phosphoric acid fuel cell (PAFC) was one of two built in the early 1980s as utility prototype demonstration plants. The other unit was in New York City, but delays associated with the approval process were so lengthy that by the time it was cleared for operation, in 1984, the fuel cell stacks had deteriorated and never produced power.

Currently, the world's largest fuel cell is an 11-MW PAFC at the Goi station, located in Ichihara City on the rapidly developing north shore of Tokyo Bay. According to TEPCO, this unit supplies enough power for about 4000 households. Fuel cell installations in Japan generally operate as cogenerators, providing useful heat energy as well as electricity. Waste heat from the Goi 11-MW unit can meet the air conditioning demands of 300 households or the heating requirements of 1300 households.

The 11-MW fuel cell plant was constructed by Toshiba Corp. with fuel cell stacks manufactured by International Fuel Cells Company (IFC) of the United States. Power generation at the plant began in March 1991. Through an agreement with TEPCO, EPRI will receive plant performance and operational data and have access to the site after key project milestones. The first of these site visits by EPRI staff and representatives of EPRI member utilities took place in March 1990. EPRI has also developed a computer-aided diagnostic tool that will help TEPCO plant operators in troubleshooting and isolating system faults.

The Japanese government expects that 1900 MW of fuel cell capacity will be installed by the year 2000. Much of this will be dispersed generation built to supply power for new commercial developments going up around Tokyo Bay. If the reliability of the Goi plant is confirmed, Toshiba plans to produce more 11-MW units at the rate of about 20 per year, with declining cost, higher efficiency, and a smaller footprint.

As well as building large-capacity fuel cell facilities, TEPCO has taken the lead in demonstrating smaller PAFC units for on-site use in commercial developments and industrial parks. As part of this program, the world's first 200-kW packaged fuel cell plant, also developed by IFC, began experimental operation at a TEPCO facility in 1988. The next year, a similar unit was the first fuel cell cogenerator installed in a commercial building. □

The world's largest fuel cell, an 11-MW phosphoric acid unit, is in operation on Tokyo Bay.

also the least developed of the three types of fuel cell currently being considered for utility use. Tests have so far been conducted on 25-kW units, and preparations are under way for building a 100-kW pilot plant within a year or so. Development challenges center on the thermal stresses imposed on numerous thin layers of fragile ceramic material in the high-temperature environment of SOFCs. EPRI intends to support the research needed to determine the feasibility of this technology and to monitor early SOFC installations, providing technical and economic data to member utilities.

"I expect that each fuel cell technology will eventually find its niche," says fuel cell program manager Ed Gillis. "Phosphoric acid cells have some advantages for cycling duty. MCFCs are the most efficient and will probably be used for baseload operation. Solid oxide units still face some fundamental technology development issues, but if these are resolved, the units could eventually be quite attractive for very small installations."

The commercialization process

EPRI studies indicate that the near-term market for 2-MW MCFC power plants is conservatively 12,000 to 14,000 MW—at a new-installation rate of 900 MW per year, once commercialization is achieved. Early applications will probably include dense urban areas facing severe environmental constraints, substation upgrades, and cogeneration opportunities in industrial parks.

Under the APPA/EPRI commercialization plan, construction of early demonstration units is expected to begin by mid-1993. If these demonstrations are successful and if utility commitments have been received within a three-year solicitation period for 100 MW or more of early production units, ERC has agreed to build a commercial-scale manufacturing facility capable of producing about 400 MW of MCFC units per year. The target price of early production units is

$1500/kW (1989 dollars). Purchasers of these early power plants would then receive royalties from the sale of future commercial units, which are expected to have prices closer to $1000/kW (1989 dollars).

"The commercialization plan offers a solution to the dilemma of how to attract enough buyers to raise production, when you need volume production to make prices attractive," says Ed Gillis. "The key is risk sharing. Orders for early production units do not require any financial commitment by a utility for at least three years, and commitments do not become firm unless the prototype demonstration plant performs successfully. In addition, there is the incentive of shared royalties from future sales and the ability to influence product design in its early stages."

The new market will need more sophisticated assessment tools if the true economic value of dispersed generation units, such as fuel cells, is to be accounted for. Such an approach involves not only comparing direct capital costs but also considering appropriate avoided costs—such as transmission lines not built because a dispersed generation unit could be installed close to a demand center.

EPRI has recently been working with the Los Angeles Department of Water & Power (LADWP) to develop an assessment methodology appropriate for dispersed generation. The initial phase of this work looks specifically at the benefits of installing 2-MW MCFCs at selected load centers. Among the benefits to be assessed are support for spinning reserve, improved load-following capability, enhanced distribution reliability, the potential for cogeneration, and environmental savings. A similar study was recently conducted by PG&E to evaluate the benefits of another type of dispersed supply option—photovoltaics.

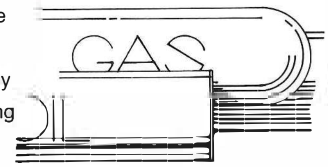
"The bottom line is that dispersed siting of some fuel cell installations will be economical—compared with other op-

The Superflexible Power Technology

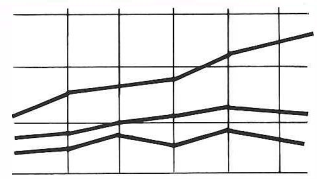
Ideal for dispersed generation, fuel cells offer attractive technical and operating advantages, including a variety of avoided costs and environmental benefits.

Siting. Because fuel cell power plants cover only a small area and produce very low emissions, they can be sited near centers of load growth, including congested urban areas.

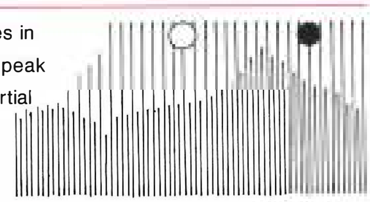
Fuel flexibility. Although early commercial units will be fueled with natural gas, it is expected that molten carbonate fuel cells will eventually use gas produced by the gasification of coal—by far the cleanest way of using this fossil fuel.



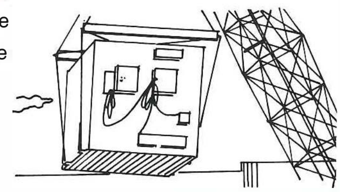
Efficiency. Fuel cells are the most efficient means of generating electric power from fossil fuels, with the conversion efficiency for MCFCs approaching 60%.



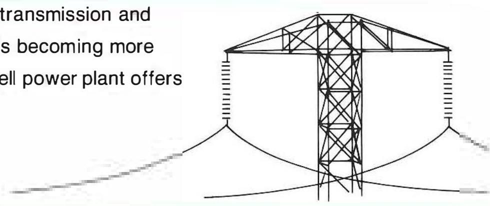
Dispatch. Fuel cells can respond to load changes in seconds—which makes them perfect for serving peak loads—and function efficiently at either full or partial power.



Modularity. The first commercial MCFC plants will be available in 2-MW modules, so utilities can add single units quickly as demand growth warrants.

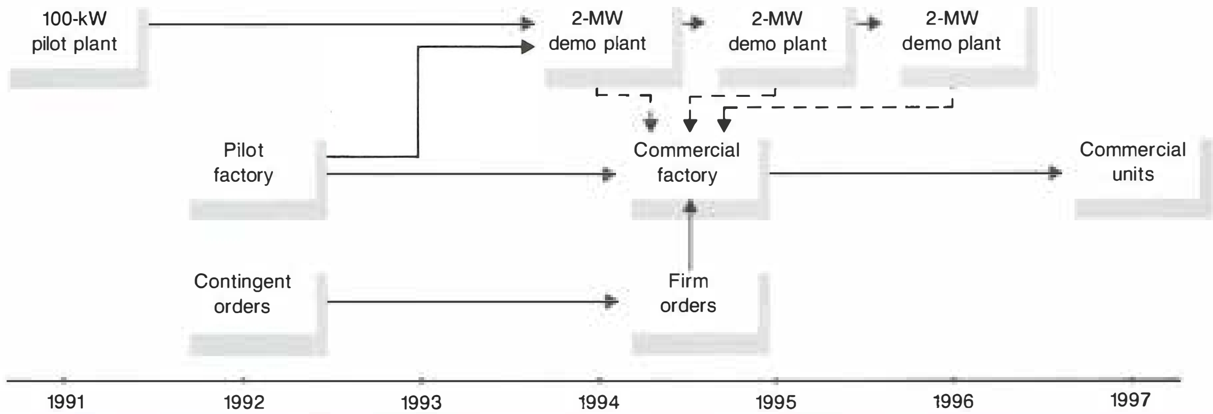


T&D deferral. Adding or upgrading transmission and distribution facilities in urban areas is becoming more difficult; installation of a small fuel cell power plant offers an attractive alternative.



MCFC Commercialization Plan

The commercialization plan for the 2-MW MCFC, based on agreements between the American Public Power Association, EPRI, and the Energy Research Corporation (ERC), calls for the construction of several demonstration plants, the first of which will begin operation in 1994. If these demonstrations are successful and utilities will commit to 100 MW or more of early production units, ERC will build a commercial-scale manufacturing facility capable of turning out 400 MW of fuel cells a year. Operation of the first commercial unit is scheduled for 1997.



tions—at $1500/kW, once you look at the full spectrum of benefits and avoided costs," Dan Rastler concludes. "Such attributes are very site-specific, however; our methodology helps utilities calculate the value of energy loss savings or deferred transmission and distribution facilities for particular cases. Distributed generation will complement central station power plants, not replace them. An expanded version of the assessment tool we're developing with LADWP could eventually be applied to photovoltaics, storage, and demand-side management, as well as fuel cells. The idea is to have a fully integrated analysis."

Looking ahead

"As a long-term strategy, we expect coal gasification to replace natural gas as a source of primary energy for fuel cells," says George Preston, EPRI's vice president for generation and storage. MCFC technology is particularly suited for this duty, since it integrates best with the gasifier. EPRI has a project under way with Dow Chemical to test a 20-kW MCFC at the company's Plaquemine gasification facility.

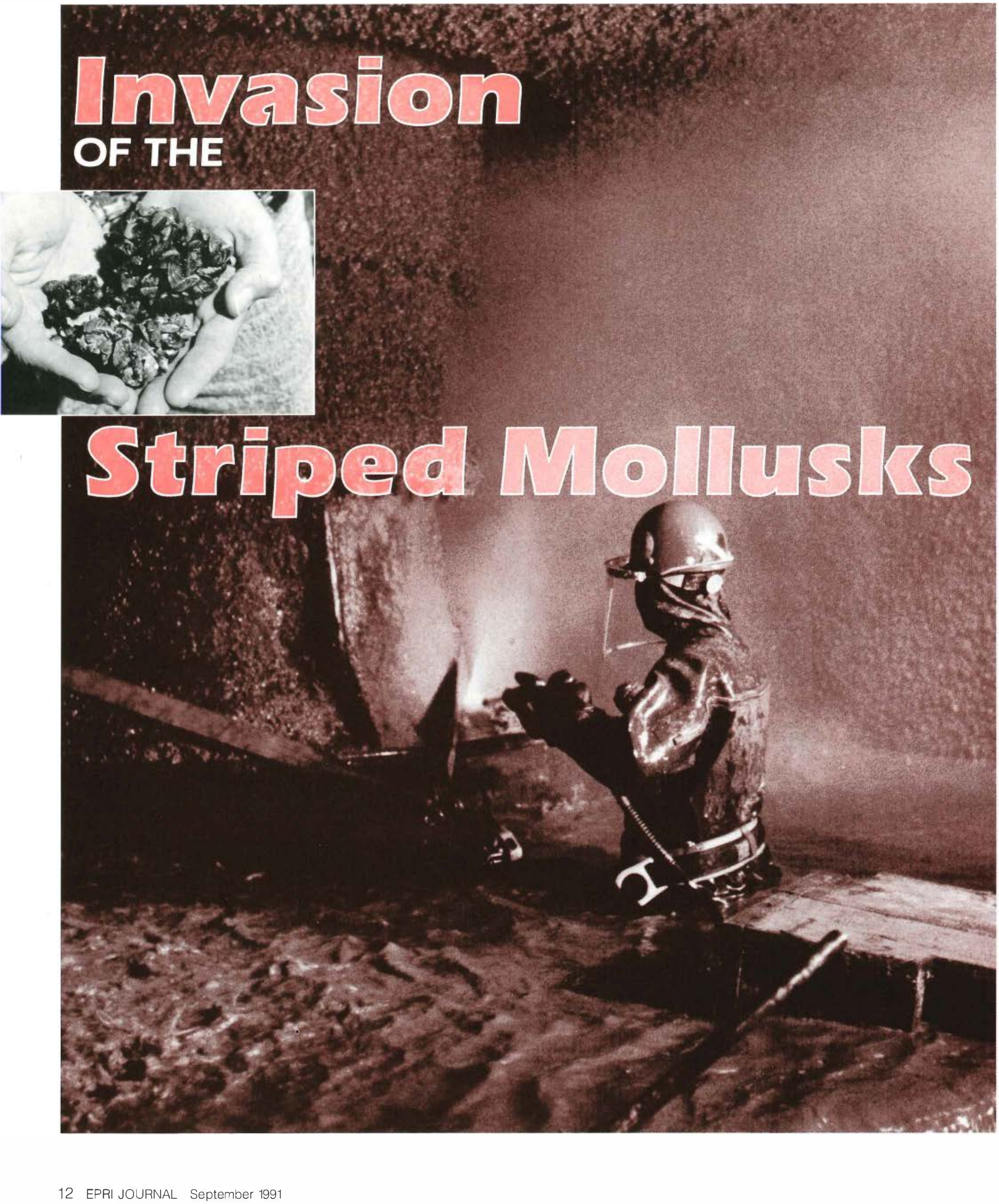
Although the electricity generation demand for natural gas—now used mostly in combustion turbines—is expected to double by the year 2000, only a fraction of this gas is being supplied on a firm, noninterruptible basis. There is reasonable probability that within a decade gas prices will rise substantially, perhaps to a level of $4–$5 per thousand cubic feet, which is the expected future cost of coal-derived synthetic gas. Fuel cells are much more efficient than turbines in utilizing either natural or coal-derived synthetic gas.

The 1990 amendments to the Clean Air Act will also play a role in making the combination of coal gasification and fuel cell generation more attractive. Over the next few years, utilities are required to halve their sulfur oxide emissions and to reduce nitrogen oxide emissions by 30%. After 2000, total emissions will be capped, and utilities will be issued emissions allowances that can be traded among "clean" and "dirty" plants. Since gasification is by far the cleanest way to utilize coal, and fuel cells are by far the most efficient way to generate power from the synthetic gas, the combination of these two advanced technologies will offer an especially attractive way for utilities to stay below the new emissions cap.

"We believe that gasification-based coal technologies will become increasingly important, first for environmental reasons and then for economic ones," says Ron Wolk, director of EPRI's Advanced Fossil Power Systems Department. "The molten carbonate fuel cell combined with a gasifier is the cleanest, most efficient coal power plant now foreseeable. It is thus vitally important that the MCFC technology be commercialized as soon as possible, with units using natural gas, so that the coming transition to gasification systems can be as smooth as possible." ■

This article was written by John Douglas, science writer. Background information was provided by Ed Gillis and Daniel Rastler, Generation and Storage Division.

Invasion OF THE Striped Mollusks



Photos by Ron Peplowski

Harry Bernhard is a busy man these days. A senior biologist at Commonwealth Edison, he happens to know a lot about a striped mollusk of great recent interest—the zebra mussel. And he's been a useful resource to a lot of people. "I've been interviewed so many times, I feel like a worn-out celebrity," he told the *EPRI Journal* during a telephone interview. Matter of fact, he explained, a camera crew from the local television station was waiting for him in a nearby room.

THE STORY IN BRIEF

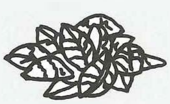
Introduced to this country only five years ago, the prolific zebra mussel has infested the Great Lakes and has already begun to move into fresh waters beyond the region. Dense populations in utility water systems have caused serious problems, reducing plant efficiency and blocking lines used for cooling and fire fighting. Experts say the striped mollusk has the potential to become the industry's worst biological problem, possibly affecting 70% of U.S. power plants. While it appears that the invader is here to stay, EPRI and others continue to develop and refine techniques to control mussel growth.

Bernhard isn't the only one. A number of utility biologists in the Great Lakes region have become experts on the bivalve (*Dreissena polymorpha*), which grows to an average length of about 1 inch. They've had to. In the three years since the first of the alien mollusks was sighted in Lake St. Clair, *Dreissena polymorpha* has infested all five of the Great Lakes and many of the water intake systems of fossil fuel and nuclear power plants in them. Some utilities have found mussel growth up to 4 inches thick on the walls in these systems. Clumps of mussels have plugged up condensers and completely blocked service water lines, increasing plant heat rate and cutting off the flow of water used for cooling and fire fighting. In the words of Paul Wiancko of Ontario Hydro, "They're the cockroaches of the Great Lakes—very prolific and hard to get rid of."

What's worse, the pesky mollusks are pushing onward at a rapid clip. Just this May they showed up in the upper Hudson River, near Catskill, New York, and in June they were found in the Illinois River, about 90 miles north of St. Louis, Missouri. The Hudson River sighting was the first outside the Great Lakes drainage basin. Experts say the mussel may have been attached to the hull of a boat that was transported by trailer from the Great Lakes region. On the basis of their thermal tolerance alone, the mussels have the potential to spread throughout fresh waters in two-thirds of the United States and into the southern part of Canada. This opens up the possibility of infestation in about 70% of U.S. power plants. "This could potentially become the industry's most widespread and serious biological problem," says Tony Armor, director of the Fossil Power Plants Department in EPRI's Generation and Storage Division.

The invasion of the striped mollusk has affected not only the utility industry. Virtually all operations that draw fresh water from infested sources have suffered, including water treatment companies and steel and chemical manufacturing firms. And while businesses have borne the brunt of the financial impact, they aren't the only ones irked. Colonies of the bivalves have been clinging to the hulls of boats, fouling fishing nets, and populating buoys so heavily they nearly submerge them. They have been eating up nutrients at a rate that concerns biologists, who fear they will throw freshwater ecosystems off balance and threaten the survival of other species, including some fish. According to the federal government, *Dreissena polymorpha*'s cumulative economic impact in the Great Lakes region alone could reach $5 billion by the year 2000.

Though the mollusks may be oblivious to the ruckus they have caused in the world above the waterline, there is no mistaking that they have prompted significant action. Last November, Congress passed a law to help fight zebra mussel infestation, earmarking about $150 million for research and control through 1995. Meanwhile, "zebra buster" squads at various utilities have taken to the waters to combat the critters. Many meetings have been called on the topic of mollusk control. Utilities—both U.S. and Canadian—are collaborating on mitigation research, sharing information with other industries, universities, and government agencies. Through the Empire State Electric Energy Research Corporation, New York State's electric utilities have established a zebra mussel clearinghouse to collect and disseminate information. EPRI is now working with the clearinghouse to make a zebra mussel database available on the Institute's electronic network, EPRINET.



Infestation has reduced the delivery capacity of water companies on the U.S. side of Lake Erie by as much as 60%.

At EPRI, a zebra mussel task force and utility advisory group have been established and operating for more than two years. The six-member task force, made up of representatives from three divisions—Generation and Storage, Nuclear Power, and Environment—was created to coordinate EPRI's research. The 25-member advisory group helps ensure that the Institute's research addresses member utilities' needs. Representatives from government agencies and universities have participated in briefing the advisory group.

They get around

Researchers say the zebra mussel arrived in the United States in 1985 or 1986, transported by a European ship. Apparently, the freighter drew its ballast water from an infested European port. When it arrived at its destination in the Lake St. Clair region and flushed its ballast, *Dreissena polymorpha* tumbled into a new home. To help prevent similar introductions of unwanted foreign species, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, which became law last November 29, mandates the establishment of regulations on ballast flushing in the Great Lakes region.

The zebra mussel's history has been traced back 400 years to the Caspian Sea. The mussel took more than two centuries to make its way to Europe, carried by currents and hitching rides on boats. During the nineteenth century it spread throughout the fresh waterways of Europe. That the zebra mussel didn't arrive sooner in this country is a wonder that has been attributed to dirty water—in the major harbors of Europe and the United States—which made it difficult if not impossible for the organism to survive. Water quality has since improved significantly on both continents; major improvements in this country began in the 1970s, with the establishment of environmental controls.

Once here, the mussel certainly didn't waste any time getting around. Helping it in this capacity is its ability to proliferate at an alarming rate. Females can produce between 10,000 and 1 million eggs per year, depending largely on their size. Even if only a small percentage of these eggs are fertilized and survive into adulthood (one biologist estimates that less than 5% make it), that's more than enough to cause some serious damage.

Another factor contributing to this mollusk's mobility is its capacity to keep itself afloat as a veliger larva directly after hatching. Water currents can swiftly spread the veligers into new terrain. Zebra mussels can survive in temperatures as low as 32°F and can initiate reproduction and maintain growth at temperatures above 54°F. (Spawning seasons in this country have typically run from May to October.) Generally, the mussels are intolerant of temperatures above 90°F, so they are unlikely to extend deeply into the southern and southwestern United States, where water temperatures commonly approach 82–90°F.

Also helping this itinerant mollusk along are its byssal threads, which allow it to cling to the hulls of boats. While similar to those of the saltwater blue mussel, these clumps of hair are not found on any other freshwater bivalve in North America. With these threads, the zebra mussel can attach itself to virtually any hard surface that happens to be handy. And as one might suspect, the water intake systems of utilities do very nicely. The shells of fellow mollusks are also quite convenient. The zebra mussel can produce up to 12 byssal threads daily. They are continually replenished throughout the mollusk's average life span of six years. And so the zebra mussels quietly gather, one atop the other, just where utilities least want to see them.

Utility intakes are more than just handy, however. Most provide a downright cozy living arrangement for the mussels. In the intakes, they are guaranteed a regular supply of fresh nutrients and oxygen, as new water continuously sweeps by. As long as the velocity of the water flow remains below about 5 feet per second, veligers can settle, secure themselves with byssuses, and become

Keeping Utilities Busy

The zebra mussel's capacity to proliferate at an alarming rate requires that utilities continuously monitor infestation and remove dense populations to keep growth under control.

Diver collects infested clams from Lake Erie

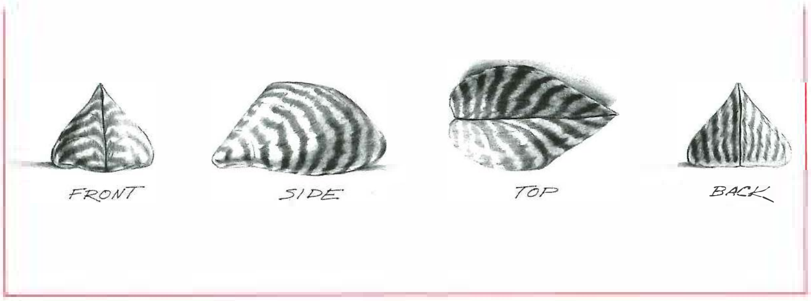
Zebra mussels and their offspring populate a clam

Mussels infest utility machinery

Removing mounds of mussels from a pump house

The Zebra Mussel in Perspective

The alternating light and dark stripes adorning *Dreissena polymorpha's* shell give the mollusk its popular name. Averaging about 1 inch in length, zebra mussels typically live four to eight years. The mussel's byssal threads, which grow from the flat side of its shell, allow it to attach to hard surfaces like the walls of utilities' water intake systems.



adults. Once attached, the mussels can withstand flow rates of up to 6.5 feet per second. Another advantage of the intakes is the dimly lit environment; these creatures are not fond of light.

Tunnels beyond the water intake systems, further into utility plants, provide some protection during frigid winter months. Bob Henderson, who is handling zebra mussel control at Niagara Mohawk's Dunkirk station on Lake Erie, notes that water temperatures at the screen houses typically range from 45° to 55°F when the lake outside is frozen over. "They can stay in our stations year-round," Henderson says. "To them, this is Daytona Beach, Florida." Henderson is among those who have witnessed the matting of zebra mussels; at Dunkirk station, populations have reached densities of more than 80,000 per square meter—a veritable zebra mussel carpet.

Not only can such colonization patterns slow the intake of water; severe damage can be wrought when clumps of mussels are jostled loose and carried by the flow of water to the condenser. If they plug up condenser tubes, back pressure on turbines increases, reducing plant efficiency. Zebra mussels in the veliger stage can even be swept into the service water systems, where they grow and clog critical lines used for fire fighting and for cooling heat exchangers and other system components. If enough cooling water is not readily available, capacity is reduced. As Bob Edwards, project manager in EPRI's Nuclear Power Division, points out, the potential impact is even more significant in nuclear plants.

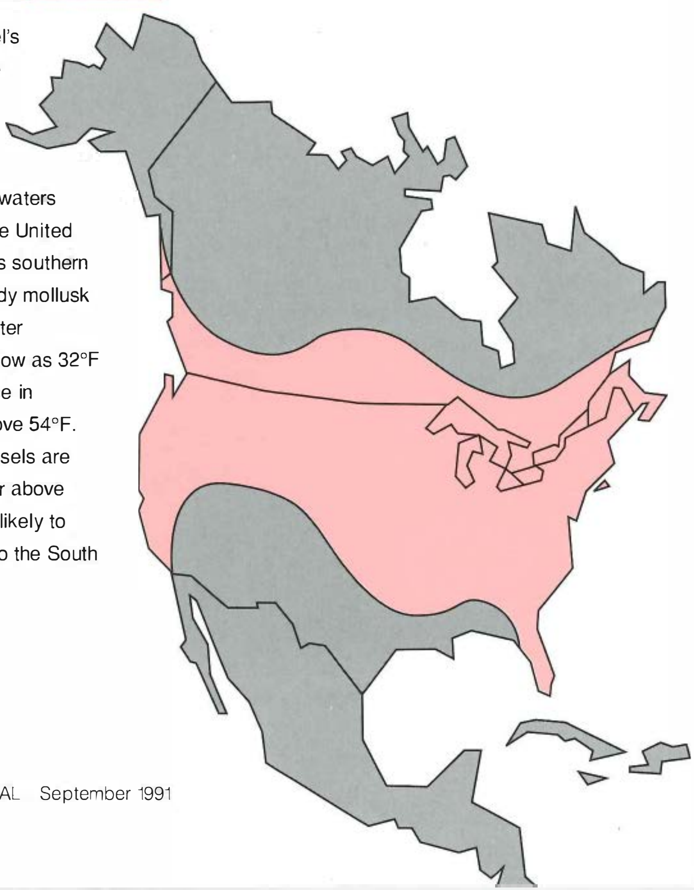
Unfortunately for utilities and others suffering from the zebra mussel impact, these creatures have few natural predators. Only some diving ducks and certain bivalve-eating fish—the common carp and the freshwater drum—appear to have developed a taste for them. The ducks are reportedly arriving in the western basin of Lake Erie in greater numbers. But even if other domestic species begin feeding on *Dreissena polymorpha*, "they're probably not going to make a big enough dent in the population to solve the problem," predicts Jack Mattice, senior project manager in the Environment Division at EPRI.

Feeling the impact

Biologists and others marvel at the zebra mussel's knack for causing trouble so quickly. Bob Peoples, resource analyst with the U.S. Fish and Wildlife Service, compares its impact to that of the Asiatic clam (*Corbicula fluminea*), which arrived in the 1930s and is costing U.S. electric utilities more than $1 billion a year. "*Corbicula* was in this country for 20 years before it caused any serious damage," Peoples says. "Zebra mussels were in this

Potential Spread

The zebra mussel's thermal tolerance gives it the potential to spread throughout fresh waters in two-thirds of the United States and across southern Canada. The hardy mollusk can survive in water temperatures as low as 32°F and can reproduce in temperatures above 54°F. Because the mussels are intolerant of water above 90°F, they are unlikely to extend deeply into the South and Southwest.



country for only three years before they shut down a water system." Peoples is referring to the Monroe, Michigan, water department on the western end of Lake Erie, where a combination of zebra mussels and ice jammed a 24-inch-diameter pipe.

Among electric utilities, Detroit Edison was the first to spot the zebra mussel on its premises. In August 1988, only two months after the first sighting of the mollusk in Lake St. Clair, utility workers found a small number of the invaders at the Monroe, Michigan, plant. Since that time, zebra mussel populations have grown so dense, they've led to "some interesting close calls," says Bill Kovalak, a biologist for the utility. One incident nearly prompted the shutdown of all four units at Monroe—a total of 3000 MW and a third of the utility's generating capacity.

Also hard hit has been Centerior Energy, which detected the striped mollusks about a month after they showed up at Detroit Edison. According to Tom Mueller, who is coordinating zebra mussel control at Centerior, the bivalves came very close to shutting down a 650-MW fossil fuel unit at Avon Lake, about 20 miles west of Cleveland. Mueller says they plugged up an oil cooler so badly, it was not sufficiently cooling the oil for the bearings of the main turbine. The temperature rose extremely close to the trip point before utility workers were able to switch over to the auxiliary cooler. They extracted nearly 40 gallons of mussels from the infested cooler, which lay deep inside the plant.

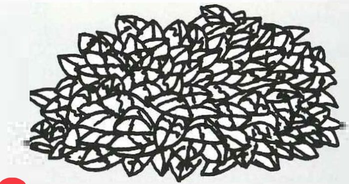
At another 650-MW fossil plant of Centerior's, the Bayshore station in Toledo, clumps of the mussels that broke free from a 4-inch-thick mollusk carpeting on the walls of a condenser circulating-pump well caused severe plugging problems. The plant's four units had to be derated a total of 12 times during the summer of 1990 while the condensers were opened up and cleaned out. Load was reduced 50% each time a condenser was cleaned. About 80 gallons of *Dreissena polymorpha* were extracted from each condenser. Mueller estimates the utility lost up to 20,000 MWh of power during the deratings. Minor plugging at other Centerior plants has become so commonplace, "it's now almost a matter of routine maintenance," Mueller says.

But not all utilities in the Great Lakes region have been hit hard yet. Bernhard of Commonwealth Edison says his utility's first sighting occurred late in the fall of 1990 at the Stateline station, at the southern end of Lake Michigan. Population densities were very light—about 10 organisms per square foot, he says. Infestation since has increased to as many as 290 organisms per square foot, and the mussels have been detected at other plants. "It has not been a significant problem yet, but the potential is there," Bernhard said during an interview in mid-July.

As experience has shown, mussel infestation can go from nonexistent to a problem of emergency proportions in a matter of weeks. (Generally, settlement occurs less than two weeks after the release of eggs.) Like other utilities, Commonwealth Edison is keeping a close eye on growth through monitoring programs, setting out blocks for the veligers to settle on, and examining water samples to detect mussels in their earliest larval stages. Regular updates to the media also are keeping the utility busy.

In the meantime, biologists are closely watching Lake Erie, where water clarity has increased tremendously since the arrival of the zebra mussel. While aesthetically this looks nice, it may not be a good sign. It means that zebra mussels are gobbling up algae and other key nutrients in the water that a number of other species, including fish and zooplankton, rely on to survive. "There's a lot of concern, and it seems warranted," says Mattice of EPRI. "This is an organism that enjoys a lot of natural advantages, and it's cropping immediate plant production. It's a short circuit in the food chain."

Another concern is that since the mollusks tend to take over virtually every accessible hard surface, they will ruin fish spawning grounds. Both commercial and sports fishers are worried. "There is such a broad spectrum of impacts on such a broad spectrum of groups," says Peoples, who has been working on nonindigenous species issues for a number of years. "Zebra mussel infestation has the potential to be as severe as or worse than anything we've ever seen, including fire ants, Medflies, and Dutch elm disease."

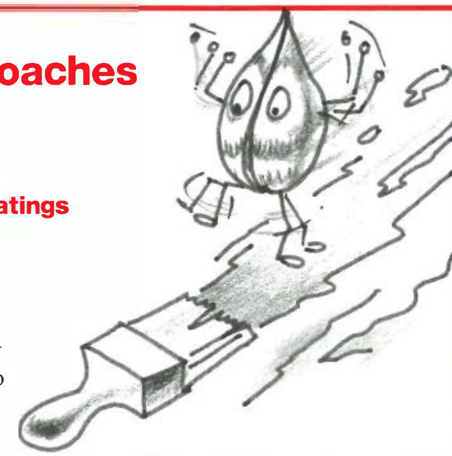


Only six months after Niagara Mohawk rid Dunkirk station of zebra mussels, the invaders were back—at densities of 80,000 per square meter.

Living with them

Frankly, *Dreissena polymorpha* caught the utility industry off guard, as did *Corbicula* when it arrived in the 1930s. Utility plants, which had been built and operating long before these foreign bivalves first found their way to the North American continent, simply have not been designed to cope with them. "Fresh waters here never expected to see either the zebra mussel or the Asiatic clam. There were no freshwater macrofouling bivalves in the United States," says Robert McMahon, director of the Center for Biological Macrofouling Research at the University of Texas in Arlington. McMahon was the principal investigator for the EPRI report *The Zebra Mussel: U.S. Utility Implications* (GS-6995), published in November 1990.

"Zebra Busting": Four Approaches



Thermal treatment

If the appropriate system components and design are available, thermal treatment can rid cooling-water intake systems of zebra mussels. This is accomplished by reversing the flow of heated water or otherwise altering its path so that, rather than being discharged, it is circulated back through the condenser and into the intake structure. If temperatures of at least 95°F are maintained for two hours, the procedure can be 100% effective. There are a number of other effective combinations of temperatures and exposure times; the optimal balance will depend on plant characteristics and the severity of infestation. Thermal treatments should be repeated two or three times a year, ideally during the mollusks' juvenile stage, when they are small enough to pass through piping systems and exchangers without causing blockage.

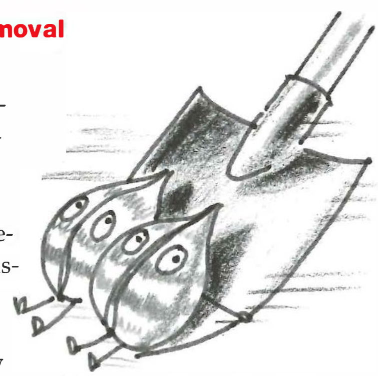
Chemical control

Both oxidizing and nonoxidizing chemicals have proved effective in controlling zebra mussels. Oxidizing chemicals, such as chlorine and bromine, can be used either as a preventive mechanism to deter mussel settlement, or to kill the mollusks once they have settled. The mussels can sense oxidizing chemicals and will close their shells for protection. For this reason, if these chemicals are used after settlement, treatment must continue until the bivalves open their shells—perhaps as long as two or three weeks. Nonoxidizing chemicals work differently; the mollusks cannot sense them, and continue feeding. Nonoxidizing chemicals that have been tested for use against zebra mussels include ClamTrol CT-1, Bulab 6002, and H-130. EPRI is seeking patents for new nonoxidizing compounds.

Component coatings

Special coatings on intake system components can make it very difficult for mussels to settle. A recent two-year EPRI study of about 30 coatings identified three silicone-based products that are effective against the saltwater blue mussel. These coatings—Bioclean, Biox, and Intersleek—are expected to be useful also against the zebra mussel. Blue mussels and other marine organisms have largely been unable to attach themselves to these coatings. If they do manage to cling, their weight tends to make them drop off before they are full-grown. Any attached mussels can be wiped off relatively easily. The coatings are typically 80% successful in preventing growth; surface imperfections, among other variables, can reduce effectiveness. Niagara Mohawk is now testing these and other coatings to see how they will fare with zebra mussels.

Mechanical removal



Virtually every utility that has experienced infestation has developed some mechanical means of removing zebra mussels. Techniques have been developed for both dry and wet environments. Some utilities have drained their intake systems and manually scraped away the mussels, hosed them off with a high-pressure water jet, or blasted them off with abrasive materials such as sand. Other utilities have sent divers or robots into wet intake systems to scrape or blast mussels off and vacuum them away. In both wet and dry environments, the process is time-consuming. At one utility it took six people—working in shifts around the clock—about five days to clean a screen house.

Because the blue mussel populated the sea waters of this continent long before the first incandescent lamp was invented, utilities learned to adapt to its existence early on. Typically, saltwater intake systems of U.S. plants are designed to be isolated for periodic cleaning. Similarly, with the zebra mussel in Europe—thanks to a century and a half of experience with the mollusk—utilities are better designed to cope. Plants with freshwater intake systems often have deep water inlets with sand filters to keep veligers out. Many plants are built with two intake systems so that one can be shut down and cleaned out while the other is still operating.

As reluctant hosts to the zebra mussel over the past three years, U.S. utilities are learning quickly how to make their environments less attractive to the pests. Power plants have experimented with a variety of control techniques. These range from conventional methods, such as scraping away the mollusks, to innovative approaches like using ultrasound to discourage veliger settlement, and even pressure treatment in attempts to kill them. Electrocution and oxygen depletion also have been tested as means of wiping out the invaders.

While a number of control techniques have been proved effective, not all are economically or physically practical for utilities. EPRI's research has identified four categories of cost-effective methods for controlling the growth of zebra mussels. They are mechanical removal, chemical treatment, thermal backwash, and coating applications. (The sidebar offers brief explanations of these techniques.)

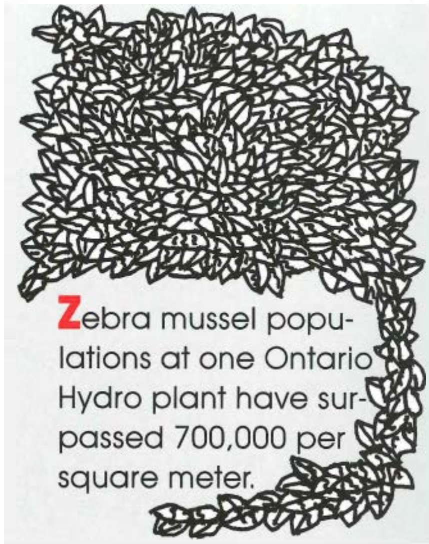
The Institute is now completing a comprehensive guide on monitoring and controlling zebra mussels, which includes details on these techniques, drawing illustrations from actual field tests. The guide also explains how plants can be retrofit to better cope with zebra mussels. It is expected to be published by the end of the year. "No one method can cure the zebra mussel problem for all plants," notes John Tsou, an EPRI project manager responsible for macrofouling control technology. "Each plant has to evaluate its own situation to determine the best method. Most of the time a combination of methods is needed."

Among the Institute's current work is a project undertaken with Centerior Energy to test a number of chemicals for their effectiveness against *Dreissena polymorpha* at various concentrations and exposure periods. During the 1990 spawning season, Centerior tested a number of oxidizing and nonoxidizing chemicals already available on the market. This spawning season, Centerior is testing nonoxidizing compounds identified by EPRI. The Institute has submitted patent applications for these proprietary molluscicides and has licensed Union Carbide to commercialize them. "What EPRI is attempting to do is bring to market new compounds that are more acceptable environmentally and also more efficacious in handling the zebra mussel," says EPRI's Edwards, who is managing the project.

According to Edwards, the commercialization strategy is to make the compounds available to EPRI members while maximizing market penetration in nonutility industries. Centerior's field tests are designed to demonstrate product efficacy, while laboratory tests by Union Carbide will develop the environmental profiles necessary to register the products with the Environmental Protection Agency. Although it is impossible to forecast the EPA's response, Edwards says, preliminary data from field and laboratory work are promising.

Industrywide, it appears that the battle against the zebra mussel has just begun. A number of utilities—both U.S. and Canadian—have initiated their own zebra mussel control projects. Niagara Mohawk is among them, having launched major studies on squelching mussel growth with chemicals, coatings, and heat treatment. Ontario Hydro, a member of EPRI's utility advisory group, has been spending an average of $1 million a year on research alone, exploring the use of ultraviolet light, pressure, acoustics, and other techniques. Current work in the industry also includes the search for some biological means of controlling the zebra mussel, such as a virus that will not affect other species.

One hopeful note is that typically in a new environment, foreign species experience a population explosion before their numbers level off and ultimately begin to decline. While the pattern does not by any means forecast a disappearance of the zebra mussel, it does suggest that their numbers will decline to a lower and perhaps more manageable plateau. The decline usually occurs after about 10 years, as food supplies dwindle and disease spreads. Biologists and ecologists can only wait and see whether the pattern will hold true for the zebra mussel. In the meantime, it appears that—as with lightning storms and other natural phenomena—utilities must learn to deal with the alien mollusks. Says McMahon, "I think we're most likely going to end up having to live with this animal. It's here and it's probably here to stay." ■



This article was written by Leslie Lamarre. Background information was provided by Tony Armor and John Tsou, Generation and Storage Division; Jack Mattice, Environment Division; and Bob Edwards, Nuclear Power Division. Other members of EPRI's zebra mussel task force are Babu Nott and Michael Miller, Generation and Storage Division.

John Sawhill Gets Things Going

Between stints in the private sector, John Sawhill ran two federal energy startups during the 1970s and early 1980s and also had time to serve as president of New York University. Now president of the Nature Conservancy and a member of EPRI's Advisory Council, Sawhill applies his experience toward promoting energy and environmental policies we can all live with.

John Sawhill has made a dozen moves in his working life, and almost every one, he says, "has been into a situation calling for a lot of change—a unique creation, like the Synthetic Fuels Corporation, or a new direction, like the energy group at McKinsey & Company, or a complete administrative break with the past, as in the presidency of New York University." He pauses and then adds, "I think startups and change are what I do best."

Now he has been president of the Nature Conservancy for a year and a half, putting a new spin on its work in environmental protection. Sawhill insists that the conservancy is the most entrepreneurial organization he has ever worked with. "Basically, what we do are real estate deals—except we buy to protect, not to develop." The 40-year-old purpose of this activity is species preservation—animals, birds, fish, plant and wildlife communities—by protection of the lands and waters they need to survive.

EPRI tapped Sawhill for membership on its Advisory Council in the spring of 1990. The Council membership of 25, prescribed by EPRI's charter, always includes seven state utility regulatory commissioners; otherwise, members are invited from a variety of professions and societal interests, such as education, science, manufacturing, economics, law, public health, and civic affairs. Individually and collectively, Sawhill and his colleagues advise President Richard Balzhiser and other EPRI executives, particularly as to the Institute's research directions and priorities.

The imprint of education

Baltimore was Sawhill's home for many years—it was where he lived as a boy, as well as his own family base for eight years. But his real center was an intellectual one. Sawhill's father ran a small manufacturing business; his mother managed the home, and she did so with the spirit and convictions of one who had traveled the educational path. "My mother could point to her own academic career," Sawhill remembers: "Phi Beta Kappa and a college degree at the age of 18. She had very high standards, very high expectations, and all of us—I and my younger brother and two sisters—were encouraged and pushed to do well in school."

Family vacations on the Delaware coast figure in Sawhill's recollections, and so do high-school football and wrestling, but book learning was the focus. He attended a small, cohesive private school and graduated in a class of 30; he and his classmates were virtually "on automatic" when it came to college. "About a third of us went to Princeton, another third to Harvard or Yale, and the rest to Virginia and Johns Hopkins."

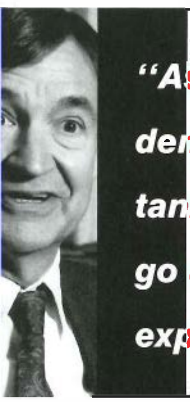
Princeton was Sawhill's choice, and when he bit, he bit hard—selecting the university's Woodrow Wilson School. His interdisciplinary curriculum there cut across political science, economics, history, and sociology; assigned him a different public policy issue to analyze each year; and led him to a 1958 degree in public and international affairs. Thus the stage was largely set for Sawhill's later service in two presidential administrations and four federal agencies, but first he got married and went to work for Merrill Lynch & Company.

Graduate school was already on Sawhill's mind, and two years later, now with a baby son, John and Isabel Sawhill turned toward New York University. By 1963, John had a PhD in economics and stepped into an NYU assistant professorship. A year later Isabel had her PhD in economics too, their son was four years old, and John was also an assistant dean of business administration.

The intellectual thread remains intact. The younger Sawhill is now in his early 30s, a graduate of George Washington University and the MIT business school; he is married, and a grandson named John II has joined the line. Sawhill himself held a full professorship at NYU when he served as its president in the latter 1970s, and Isabel Sawhill is now a visiting pro-

fessor at Georgetown University law school. In fact, when John Sawhill is asked about influential contemporaries, he responds without hesitation, "My wife. She's a trained economist and deeply involved in public policy matters. But her main career has been as a senior researcher at the Urban Institute in Washington, and one of our frequent sparetime activities is talking about public policy issues."

McKinsey & Company, Sawhill's employer from 1965 to 1968, proved to be a turning point in his experience. He recalls his own deliberate agenda—joining McKinsey's Washington, D.C., office because he was most interested in doing government work. But as matters turned out, he was assigned to the one private client there, Sun Oil. This was his first exposure to the energy business, and "I spent a lot of time in Texas. I read a lot of geology and engineering books. Oil is so big; it's so international; it has such an impact on our lives and our standard of living."



"As the energy crisis took hold, people lost faith and confidence in the government. You know, there were rumors of oil tankers sitting offshore, full of oil, just waiting for the price to go up. We at the Federal Energy Administration would try to explain, and people didn't believe us."

Solving energy problems

The McKinsey cachet and experience followed Sawhill afterward: late in 1972, after Richard Nixon's reelection, he got a phone call from the White House. It was an offer to join the Office of Management and Budget as associate director for energy, science, and natural resources. Sawhill was fascinated: "Just the idea of working on public policy questions. Coming into a new administration, too, because Nixon was expected to focus more on domestic policy during his second term. Also, a chance to work in the energy field. And, of course, the leverage you get in OMB."

The next two years were a whirlwind of events and stress. Watergate had occurred and would become a paralyzing presidential issue as rumors and allegations became the subpoenas and congressional hearings that led to Nixon's resignation. The OPEC oil embargo came in 1973, and the ensuing energy crisis—both the facts and the perception—washed across the nation in confusing eddies of price spirals, hasty government action, lines at gasoline stations, and another complex of rumors and allegations that pitted federal agencies, oil companies, and other parts of society against one another.

Was Watergate just another news story for Washington workers, or did it affect life in the OMB? And what about the Federal Energy Administration (FEA), created by Congress in 1974, of which Sawhill was named the first administrator? His answer is quick and candid. "Nixon and his advisers were so focused on Watergate that it meant the rest of us were spending a lot of time running the government. We had a lot more responsibility—and probably a lot more freedom—than we might have had otherwise.

"But also, and increasingly, as the energy crisis took hold, people lost faith and confidence in the government." Sawhill's memory is obviously clear, strong, and personal. "You know, there were rumors of oil tankers sitting offshore, full of oil, just waiting for the price to go up. We would try to explain, and people didn't believe us."

Sawhill is willing to second-guess his actions in those days. The problem was real, of course: oil was being embargoed and prices were going up. "Less oil was coming into the United States than before. There would inevitably have been some shortages. But if we'd had no price controls and no allocation system, the market would have handled it, I think."

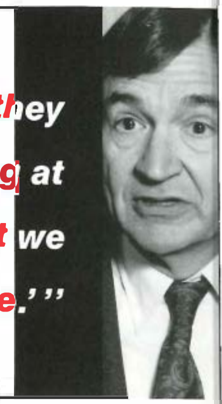
Most of all, though, at the time, it was the pace, says Sawhill. "We went to work at 7 in the morning, and about 11 at night we'd order a pizza, figure out what we'd done that day, and then go home." And there was pressure, he adds. "Everyone wanted information. I remember one day that I testified before Congress four times. And besides that, individual congressmen wanted to appear on TV with me."

Sawhill also remembers an up-note, however: establishing a federal energy research capability. "When I became FEA administrator, we had none, so I contacted Alvin Weinberg, director of the Oak Ridge National Laboratory. I asked him to create a small FEA research office in Washington, and it was out of that office that ERDA grew." Sawhill's image is sweeping and simplistic, but the Energy Research and Development Administration was where disparate research groups of two or three executive departments—and the FEA and the Atomic Energy Commission—first came together, and from which in turn came today's Department of Energy.

A point of policy disagreement ended Sawhill's first turn with the federal government. Indelibly imprinted by U.S. dependence on oil from an ever-unstable Middle East, he concluded that other crises would surely follow unless something was done about the demand side of the equation. "I pressed hard for the administration to take strong energy conservation measures, particularly to push for a higher tax on gasoline. Eventually, I made the political mistake of saying this on the 'Today' show, and the White House switchboard lit up like a Christmas tree."

Nixon was now gone, and President Gerald Ford, being from Michigan, didn't favor further taxation on automotive travel. "I had a meeting with him," says Sawhill, "and he said, 'You know, John, this isn't part of the administration's program.' And I said I couldn't be comfortable if it wasn't, so we parted company. It was time for me to leave."

"Most companies let the future happen to them, and they react to it. But others create their own future by looking at the forces working in society and saying, 'Here's what we can do to shape those forces—and thereby our future.'"



Turning around and starting up

New York University was a startling opportunity for Sawhill. He was invited to become president of his alma mater, the largest private university in the country, before he had even been to his 20th reunion. But Sawhill had lived with high expectations for years; he had undeniably been on the fast track, and that very conditioning made the NYU presidency tenable for him at the age of 39.

"I'd always had very high expectations of myself," he says in an analytical, detached way, "so I didn't look upon the appointment as a prestigious position so much as a lot of challenge I had to deal with." Sawhill elaborates: "The university was on hard times. Economic circumstances had forced it to sell off a campus in the Bronx, and that had disaffected a lot of alumni. The endowment had shrunk nearly to zero, the budget deficit was mounting, and students weren't exactly clamoring to attend, because New York City itself was in bad shape."

In the circumstance, Sawhill saw himself as more of a leader than an educator. He sought to pull the university community together, to revive its pride in NYU's size and intellectual strengths—and to draw on the undeniable civic and cultural assets for which New York itself is renowned. The upshot was a three-year campaign that raised $115 million, highlighting an academic and financial turnaround that the *New York Times* called a miracle of higher education.

Sawhill was thus well established, and he expected a long relationship. But again the phone rang, and this time it was Jimmy Carter calling, asking Sawhill to become deputy secretary of energy. The DOE appointment turned out to be an important door opener; a year later Sawhill was named chairman and CEO of the Synthetic Fuels Corporation. This was a unique and aggressive federally sponsored push to develop, prove, and scale up new domestic fuels and energy technologies. Sawhill was familiar with the plan, having been involved in its enabling legislation. Also, he adds, "I still felt as I had in 1975, but if we weren't going to do anything on the demand side of the equation, I thought, we'd better do something on the supply side."

Given the price of energy in 1980—"and where we thought it was going," Sawhill interjects—the novel corporation seemed plausible. For a professional policy strategist and public administrator, it was made to order. "It was an experiment," Sawhill says flatly. "We had expedited contracting practices. I could bring people in from the private sector. We could really cut through a lot of the red tape of typical government bureaucracy."

But the Synfuels Corporation clock ran down rapidly. Beginning in 1981, the Reagan administration applied its philosophy that if an industry was potentially viable, the private sector would create it; if it wasn't, then the government shouldn't back it. In addition, energy prices collapsed, making it clear that even greater federal support would be needed than originally planned, and "in commercial terms," as Sawhill phrases it, we've had an oil glut ever since.

Returning to McKinsey, this time as a partner, director, and the head of energy consulting, Sawhill thoroughly integrated the lessons of Sun Oil, OMB, FEA, DOE, and Synfuels. A feature of his work came to be the direction of strategic planning studies with and for some of McKinsey's larger energy industry clients.

Sawhill is an absolutist on strategic planning. "Most companies let the future happen to them," he says disapprovingly, "and they react to it. But others create their own future by looking at the forces working in society and saying, 'Here's what we can do to shape those forces—and thereby our future.'" Identifying the swing forces is critical; Sawhill cites markets—both those that are already forming and can be exploited and those that can be created. He also cites government regulation, obviously a key force for utilities and for changing public attitudes and lifestyles.

Electric utilities tend to be skittish about regulatory bodies, and this colored their response to some of EPRI's early R&D, mainly in air pollution but also in nuclear safety. Wouldn't the advent of better technology only hasten tighter standards and across-the-board requirements for expensive add-ons to power plants? Sawhill believes such a perception is short-sighted. "You're either ahead of the curve or you're behind it. If you try to anticipate and shape regulation, you're ahead of the curve. If you simply accept what comes, you're behind it. What's wrong, it seems to me, is for companies to complain about regulations created by others rather than to try to lead the regulatory process."

Applying energy to the environment

Sawhill's years with both the federal government and McKinsey added contacts and understanding that are valuable today in his presidency of the Nature Conservancy. He had been a director of Consolidated Edison while president of NYU; now he has become a director of Pacific Gas and Electric.

He chairs the board of the Whitehead Institute for Biomedical Research, an activity that takes a good 10% of his time and has been important to Sawhill for more than 10 years. And for the past five years, he has been a Princeton trustee, understandably focusing on the Woodrow Wilson School and helping the university improve the quality and effectiveness of its public policy curricula.

Also five years ago, New York Governor Mario Cuomo appointed Sawhill to chair a task force on ownership and operating alternatives for LILCO—Long Island Lighting Company. The utility was beleaguered by the cost and controversy arising out of its never-certified Shoreham nuclear plant and was targeted by some for public takeover. The task force decided in favor of continued private ownership, and LILCO is healthy today, even without the mothballed Shoreham.

By the end of the 1980s, Sawhill found himself "passively exploring opportunities in the nonprofit sector"; that is, when inquiries came his way about candidates for leadership positions in nonprofit institutions, he was becoming interested himself. When the Nature Conservancy became a possibility, Sawhill's thinking fell together. His reasons flow quickly.

"One is that I had run large organizations, and after nine years as a consultant, I was anxious to run something again. Second, my experience in the energy field had given me a lot of familiarity with environmental issues—and with many of the people and organizations involved. And third, the conservancy just fits my style and philosophy. You know," he adds with a chuckle, "Peter Drucker's latest book, on nonprofits, says it has the best strategy of any of them."

"I pressed hard for the administration to take strong energy conservation measures, particularly to push for a higher tax on gasoline. Eventually, I made the political mistake of saying this on the 'Today' show, and the White House switchboard lit up like a Christmas tree."

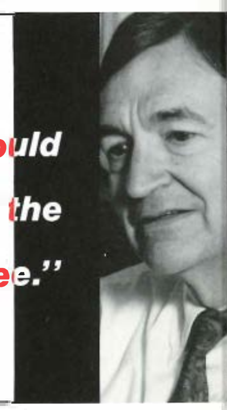
Of special appeal to Sawhill is the Nature Conservancy's scientific methodology for evaluating environmentally sensitive land. "This system—called the heritage program—is what we use to establish our land protection priorities," he says. "We don't buy land because it's pretty; we buy it because it has significant ecological value." Like the conservancy's mission, this echoes conservationist Aldo Leopold, who wrote, "If the land mechanism as a whole is good, then every part is good, whether we understand it or not. . . . To keep every cog and wheel is the first precaution of intelligent tinkering."

Sawhill uses a metaphor of "lifeboats" of biological diversity, all too often adrift in seas of dangerous developmental trends. This is the plight of many traditional—and limited—parks and preserves, he says; their boundaries are useless against surrounding activities that affect atmospheric and water quality, runoff patterns, erosion, food chains, and even climate. Sawhill argues for larger circles of protection—"buffer zones that can mitigate the impact on the area we need to protect. This means determining how much intervention an ecosystem can tolerate and still function. In short, how can we make economic activity and environmental protection compatible?"

The Nature Conservancy work poses hard questions, but there are also unique joys. At 55, Sawhill is unequivocal. "It's the best job in America." He talks of a recent visit to 55,000-acre Matagorda Island, off the Gulf coast of south Texas. Mostly government held, variously used as a wartime bombing range and leased as a cattle ranch, it is a winter habitat of the endangered whooping crane. The conservancy therefore bought 11,000 acres several years ago, creating a preserve since turned over to the state of Texas and the U.S. Fish and Wildlife Service.

Matagorda Island is truly a conservation showcase, according to Sawhill. "I saw 10% of the world's whooping crane population there—14 out of only 140. They're really something: 5 feet tall, with a 7-foot wingspan—extraordinary. Preserving them is a challenge, but it's also an inspiration."

"I'm a strong proponent of nuclear energy. I think we should be talking about what we can do to revive it—as one of the solutions to a lot of the pollution we see."



A double-barreled advisory role

John Sawhill cares how energy is used. And accordingly, he's interested in those who influence its use. EPRI is just such a place, he says, and that made it easy to say yes when he was asked to join its Advisory Council.

Even so, resolving some energy and environmental indicators remains a tricky business. Sawhill approvingly cites a 1990 *New York Times* poll where 80% of the respondents agreed with the premise that environmental protection is so important that standards must be raised and improvements continued, regardless of their cost. At the same time, he can be mildly cynical about the process of arriving at a national energy policy: "DOE holds hearings all around the country, talks to a lot of constituencies, gets a lot of testimony, and then tries to synthesize what it's heard. The end result is something so contentious that Congress won't pass it or so politicized that it doesn't do any good."

How does Sawhill reconcile these views? How can so many of us claim high environmental values and still be so uneven in our support of energy policy? The answer leads directly into the first of four points that recur in Sawhill's discussions of energy, the environment, and electric utilities.

"Americans have a love affair with the automobile. We call ourselves environmentalists, but we love our cars more than we love anything else." This assessment goes back to that day in 1975 when Sawhill spoke his mind on the "Today" show. As he said then, we should raise the tax on gasoline. The educational job would be immense, he admits, an unprecedented leadership challenge, but such a tax is the one best thing we could do for the environment. It would lead to less air pollution. Moreover, Sawhill says, it would be a market incentive toward more efficient, probably smaller cars. It would motivate heavier public investment in public transportation. It also would lessen our dependence on foreign oil, and, he adds, it would be a tremendous help in reducing our budget deficit.

There's irony in all this, Sawhill acknowledges. Our environmental sentiments led us to support amendments to the Clean Air Act, he says, and that's likely to raise the price of electricity. "But we wouldn't be willing to do the same thing in terms of gasoline prices. We just don't have the same love affair with the light switch that we do with the automobile."

A second Sawhill point also carries both energy and environmental policy implications—and calls forth contradictory views. "I'm a strong proponent of nuclear energy. I think we should be talking about what we can do to revive it—as one of the solutions to a lot of the pollution we see." Sawhill adds his conviction that some of EPRI's best work has been its technology support of nuclear electric utility members.

There is undeniably a great fear of nuclear energy, Sawhill admits, and the A-bomb legacy from 1945 is only part of the problem. He traces the circumstance mainly to our early nuclear administrative structure, "a close-knit little club between the Joint Committee on Atomic Energy and the AEC, which had the effect of keeping decisions about the technology out of the normal political process. When people woke up, they realized something was happening that they didn't understand and hadn't heard debated in public forums." Such management was very short-sighted, in Sawhill's view, arousing suspicions and distrust that heavily influenced our response to the Three Mile Island accident and even remain with us today.

"In the field of energy policy, then," he concludes, "it's this love affair with the automobile and our fear and suspicion about nuclear energy that are the basic problems." But Sawhill has at least two corollary ideas that carry seeds of solutions.

Thus, his third point has to do with our attitude toward our energy and environmental past. He decries the legislative philosophy that produced the so-called Superfund, by which we tax individual companies for the cleanup of wastes and pollution from years ago. "As a society we were ignorant," Sawhill argues, "and it galls me that we blame companies today for past practices that were the accepted way of doing business at the time. It's 20/20 hindsight. What we ought to do is tax ourselves collectively for the cleanup program." Sawhill is not one to point the finger, savor resistance, or further an adversary situation. Far better, he feels, is to learn what must be done and get on with it.

The power to do this, the motivation, and to a surprising extent the willingness lie with private-sector leadership. This is Sawhill's final point and one that he puts before every possible audience, where it is variously taken as a fact, a wish, or a challenge. In just a short year and a half with the Nature Conservancy, he has come to see enlightened business approaches that simultaneously produce economic and environmental advancement.

One example is the conservancy's 70-mile-long preserve of barrier islands off the Virginia coast. "We initially bought them to protect habitat for migratory and shore birds," Sawhill explains, "but we discovered that if agricultural and industrial practices on the mainland polluted the waterway in between, the preserve would fail." As a lifeboat, in his metaphor, it would be overwhelmed by the waves of pollution.

"Some CEOs don't care, and some haven't thought much about it, but by and large they're like the rest of us—they have a feeling that environmental protection is important, and they're more often acting on that feeling."

To forestall mainland industrial and agricultural effluents and the development of "condominium row," the conservancy embarked on education, bought farms, and encouraged local residents to consider zoning changes. "It turned out," says Sawhill, "that our biggest supporters are the fishermen in the coastal waterway. Their livelihood depends on keep-

"I think new companies will appear that provide new technology for electric energy efficiency. The utility industry will be more eclectic, less monolithic. We'll see some disintegration of the industry."

ing those waters clean. The best assurance that we can protect something is when local economic interests realize that it serves their purpose to help the process along."

Returning to the arguable point of America's 80% environmental commitment, Sawhill allows that "some CEOs don't care, and some haven't thought much about it, but by and large they're like the rest of us—they have a *feeling* that environmental protection is important, and they're more often acting on that feeling."

In particular, he adds, businessmen traveling to Eastern Europe have now seen what can happen when there is absolutely no control on air or water pollution. "You can see the air and walk on the water. U.S. visitors come away relieved that we haven't let this country go that way—and convinced that we must not."

Looking down the time track

Sawhill's advisory lens focuses alternately on industry matters and on public policy. It's going to be difficult for EPRI to perform in the future exactly as it has in the past, he declares. "The energy business—and utilities and EPRI as parts of it—is a moving target. Intercompany competition is increasing, and proprietary technologies are coming from different parts of the business. Furthermore, Congress is likely to accelerate these trends as it tries to permit more players to have access to power systems." EPRI must therefore continually respond to its changing business environment.

Sawhill foresees restructuring among what we now call electric utilities. There will be new entrants, he says, mostly in power generation, but also at the delivery end. "I think new companies will appear that provide new technology for electric energy efficiency. The utility industry will be more eclectic, less monolithic. We'll see some disintegration of the industry." The image is apocalyptic, and Sawhill only partially softens it by adding that events will be "a little destabilizing to some players."

His projections all hinge on economic and technological forces, and the circumstance demands strategic planning. "EPRI shouldn't try to retard these forces. It should recognize them, keep pace with them, factor them in, and support them. In due course, cogenerators should be EPRI members. And energy service companies, too—the ones that work on saving megawatts rather than using them."

But Sawhill cautions that the main issue in public policy formulation today is much broader than simply energy or environment—or health care, education, housing, or whatever. As he sees it, our whole economy is faltering. "Look at productivity growth. For a time, in the 1970s and early 1980s, its slowdown was masked by greater participation in the labor force—more two-income families, for example. But that trend has topped out, and we must face the problem head-on."

Incremental changes, Sawhill says, "are just the same old solutions plus two percent. They have little impact—sometimes even a negative impact. We need to go for more radical solutions." Brightening a bit, he adds, "I think we need a sort of Desert Storm operation here at home—radical solutions and strong leadership. If we aren't going to raise taxes, we need to shift activities away from the public sector. This could spur productivity growth."

Presidential leadership is the key factor. "It can do a lot," Sawhill says with finality. "Ronald Reagan was a very influential president. He argued successfully for tax reductions, and then he caused the tax reform of 1986. That was radical change! So we know it can happen." ■

This article was written by Ralph Whitaker, science writer, from an interview with John Sawhill.

THE STORY IN BRIEF

While heat pumps have many advantages over conventional space-heating and -cooling equipment, the decreased efficiency of air-source units in very cold weather can limit their use in northern climates. Ground-source heat pumps, which use the earth rather than the air as a heat reservoir, are inherently better suited for both very cold and very hot climates, and their use can result in significant savings for utilities and their customers alike. One particularly promising development is the installation of the ground-loop piping in residential subdivisions before the homes are built and landscaped, which greatly reduces installation costs. Meanwhile, utilities, manufacturers, and other interested parties are developing successful strategies for speeding the use of ground-source heat pumps throughout the country, with special attention to applications in the northern United States.

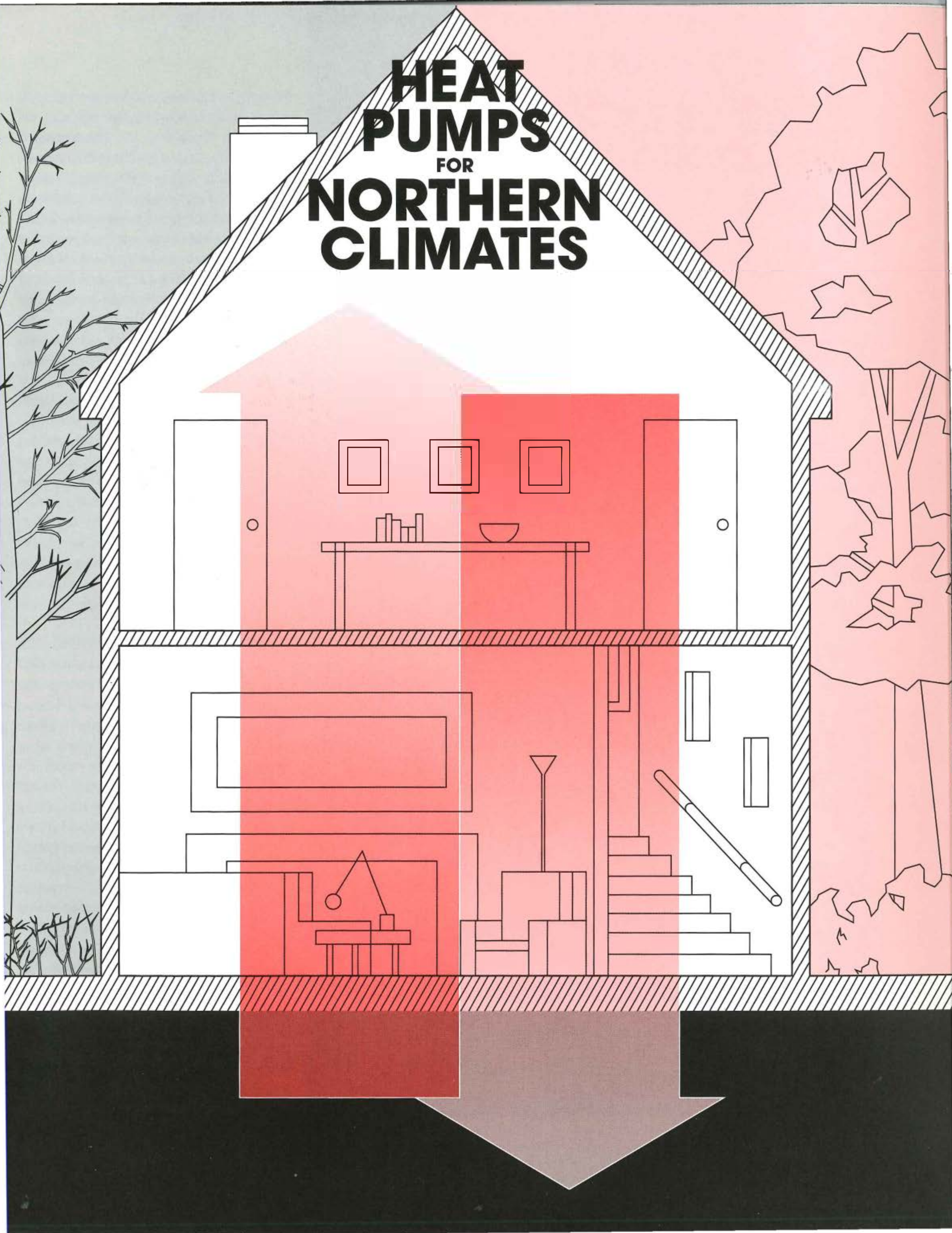
At the Walden Pond residential subdivision in Carmel, Indiana, ground-source heat pumps for 126 homes are expected to save the local utility $476,000—the present value of the increased cost of having to provide energy for more-traditional heating and cooling over 20 years. The homeowners themselves will each save about $400 a year by using the innovative, 3-ton-capacity units instead of standard gas furnaces and electric air conditioners. Savings can also be significant with equipment designed for commercial buildings. Commenting on the 92-ton ground-source heat pump installed at an Oklahoma YMCA, its director says, "We may be looking at $100,000 in savings over a 10-year period."

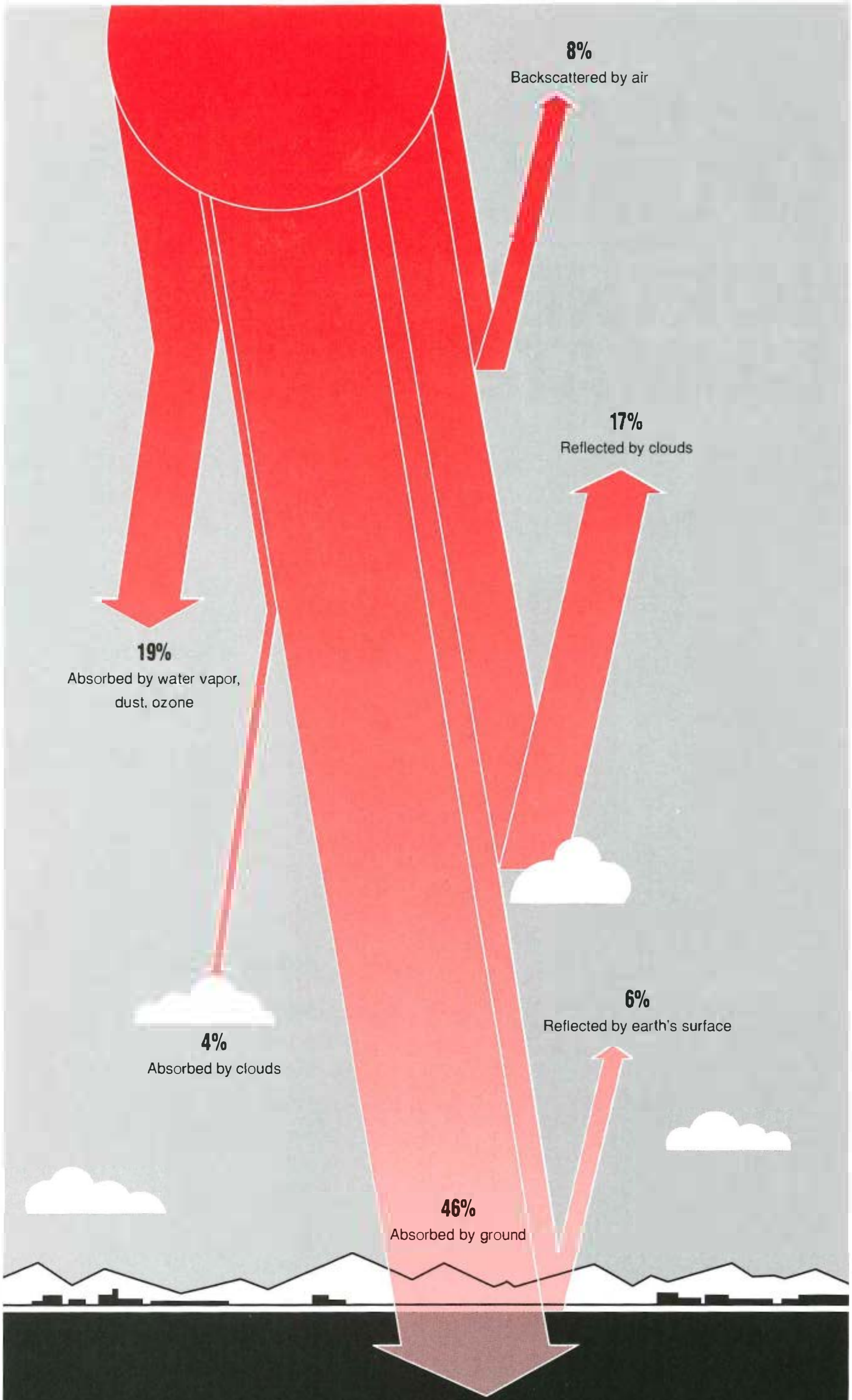
Heat pumps are unique in their blend of utility and customer benefits. As Powell Joyner, technical manager for EPRI's advanced residential projects and editor of EPRI's quarterly *Heat Pump News Exchange*, puts it, "Heat pump technologies offer utilities a way to balance load in the face of growing demand for air conditioning. This can lower consumer costs, helping to persuade those now using fossil fuels to kiss an old flame good-bye."

Interest in heat pumps rose with oil prices in the 1970s, as researchers began investigating more-energy-efficient heating and cooling systems. At that time, attention focused on conventional, air-source heat pumps, which deliver 2½ to 4 times as much energy in the form of heat (or heat removal) as they consume in electricity. Air-source heat pumps can pull heat even from outside air that is considered cool. But in areas with very cold winters, supplemental electric resistance heating is often needed on the coldest days. Likewise, the cooling capacity and efficiency of air-source heat pumps are adversely affected on very hot days.

Ground-source heat pumps (GSHPs), which transfer heat to and from the earth rather than the ambient air, are more forgiving of seasonal temperature extremes. Because the ground (including ground-

HEAT PUMPS FOR NORTHERN CLIMATES





Grounded in Solar Energy

Because the ground is massive and dense, it absorbs nearly half the solar radiation reaching the earth–double the amount absorbed by the atmosphere. In contrast to the air, the ground remains at a relatively constant temperature throughout the seasons, providing a warmer heat source in winter and a cooler heat sink in summer. The resulting higher efficiency means GSHPs cost less to operate than air-source units year-round.

water) is massive and dense, it absorbs nearly half the solar energy reaching the earth—far more than the 23% absorbed by the air—and does so with a much smaller daily and seasonal swing in temperature. The ground stays at a relatively constant temperature throughout the year, providing a warmer heat source in winter and a cooler heat sink in summer. This allows GSHPs to do well on both ends of the temperature spectrum, when utilities are particularly burdened with demand peaks.

PSI Energy (formerly Public Service of Indiana), sponsor of the Walden Pond project, was one of the first utilities to pursue the promise of GSHPs. "Most utilities," says Nancy Miller, direct marketing and sales manager at PSI, "are into demand-side management. If utilities can lower demand and even out the peaks, they not only won't have to build so many new plants but can lower the wholesale price they pay for electricity and pass the savings on to the user."

How Walden Pond works

Walden Pond is the first subdivision in the nation where ground coils for heat pumps were installed prior to home construction. Explains EPRI's Powell Joyner, "GSHP growth began in southern states like Louisiana because you have a lot of water-saturated soil there: the wetter the ground, the better the thermal contact and the less coil you have to bury, cutting the cost of both labor and pipe. But we knew that a huge market—residential and light commercial—lay to the north, if we could drive down ground-loop installation costs and convince northerners to abandon their gas-fired furnaces. Walden Pond was a step in the right direction."

The Estridge Group, Walden Pond's developer, installed closed loops of polybutylene pipe in each lot, buried horizontally in two layers, 3 and 6 feet below the surface. In lots that were too small to accommodate the horizontal configuration, vertical holes as deep as 150 feet were drilled for the pipe. The heat transfer fluid is a mixture of water and antifreeze; in warmer climates, water often works well by itself.

Walden Pond is the first of 44 subdivisions totaling 3137 homes that the Indiana utility has signed up for GSHP installation. As an incentive to developers, PSI Energy not only pays ground-loop installation costs but, using EPRI-provided technical assistance, supervises the procedure. Although high installed costs have been the primary obstacle to wider acceptance of GSHP technology, mass preinstallation reduced the average horizontal- and vertical-loop costs at Walden Pond from $3250 to $2150 per home.

According to PSI Energy's special projects coordinator, Michael C. Lyle, one of the advantages of a ground-source system is that it doesn't need an outdoor unit, as air-source systems do, so it doesn't detract from the appearance of a home's exterior. Nancy Miller says that market penetration of GSHPs in PSI's service area has risen from 2.6% in 1986 to over 10% today.

Two nonresidential installations

The 92-ton GSHP system at the Daily Family YMCA in Bixby, Oklahoma, eliminates the need for both cooling tower and furnace boiler room. Dale Isgrigg, director of the Daily Family Y, says that this cuts down on maintenance costs. The 16 indoor units are concealed within the building in relatively small spaces.

What Isgrigg calls a "showcase project" allows independent temperature control of 14 separate zones, including a day-care center, an aerobics room, and a full-size lap pool heated year-round. A 15-hp pump circulates water through 32,000 feet of sealed polyethylene pipe, buried in horizontal loops under the parking lot.

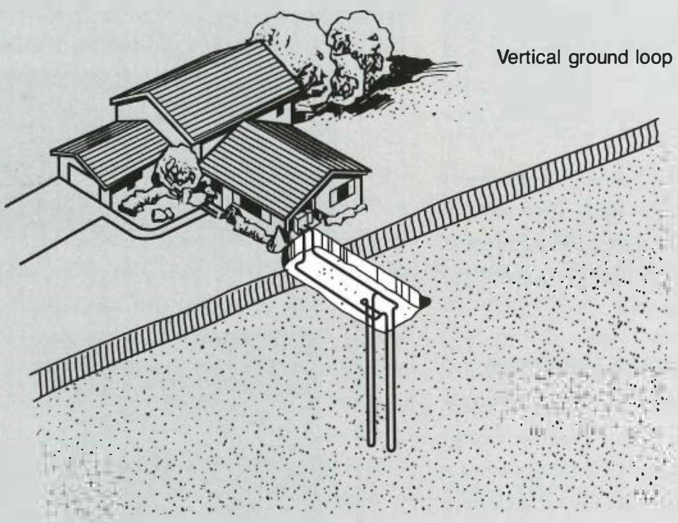
"There was some turmoil with the directors of the Y at first," states Ron Huntley, commercial sales representative for Public Service Company of Oklahoma, which, with independent engineer Jim Netherton, designed the system. "They wanted something more conventional until we pointed out potential savings." The average monthly electric bill for the first 10 months of operation was $3000—a full $2000 less than the average monthly electric bill for YMCAs of similar size.

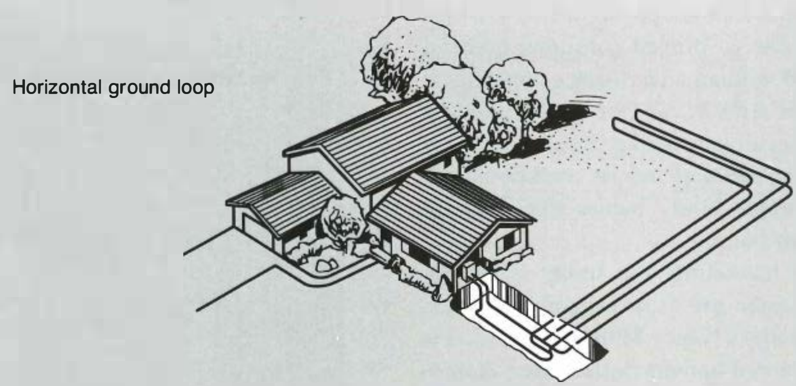
All PSO customers installing a ground-source heat pump receive cash-back incentives of up to $120 per ton of heating and cooling capacity. The Daily Family YMCA used its $10,000 payment to offset the cost of installing the ground loop. Isgrigg says, "The system works beautifully even in unusually cold weather."

Early this year Buckeye Power installed a 58-ton GSHP system to serve the 15,000-square-foot addition to its headquarters

Choosing the Right Configuration

The GSHP uses buried loops of fluid-filled plastic piping to transfer heat to and from the ground for high-efficiency indoor cooling and heating. Horizontal loops buried 3 to 6 feet below the surface are generally used where lots are large and the soil allows easy trenching. Where lots are small or the ground is rocky, the pipe is sunk in higher-cost vertical boreholes, which are drilled 100 to 200 feet down and backfilled with grout.





Art courtesy WaterFurnace International

in Columbus, Ohio. Containing a mixture of methanol and water, the polyethylene loops are installed vertically in 65 boreholes backfilled with grout, each 150 feet deep. Twenty-eight heat pumps ranging in size from 1 to 4 tons produce 3.7 units of heat for every unit of electric energy consumed.

Bernie Woller, Buckeye's director of facilities and special projects, extols the system's high degree of flexibility. "Twenty-eight zones controlled independently are particularly useful in a building like ours, where the conference rooms might have 100 people in them one day and then sit empty for several days." To further enhance the system's efficiency, Buckeye installed a direct-digital-control energy management system. Explains Woller, "It can sense the outdoor temperature and the rate at which it is rising or falling and thus can delay startup in the morning, for instance, if the temperature is rising rapidly."

Over the long haul, Buckeye's system is expected to consume 40% less energy than an electric resistance heating system with rooftop air conditioning—saving approximately $4000 a year.

Promotion strategies that work

PSI Energy, HEATAC Systems in Pennsylvania, the National Rural Electric Cooperative Association, and Oklahoma State University's International Ground Source Heat Pump Association offer promotion strategies that are paying off.

PSI Energy primed consumer demand in 1986 with an advertising campaign for System GT (i.e., GT for geothermal). It then began convincing developers to offer GSHP heating and air conditioning in new single-family homes like those at Walden Pond.

The marketing-wise utility is also licensing the use of its program. Explains PSI Energy's Nancy Miller, "System GT is a registered trademark that other utilities can make use of; we've had interest all the way from Florida to California. Their licensing agreements include referrals

Applications All Over the Map

Although ground-source heat pumps got their start in the South and are growing fastest in the middle states, they have great potential in the North. Commercial installations range from schools and churches to restaurants and office buildings. In the residential sector, the technology holds particular promise for subdivisions such as the Walden Pond project, where GSHP loops were economically installed prior to home construction.

Installing horizontal ground loop

Messiah Lutheran Church, Minnesota

Menchaca Elementary School, Texas

Elston home, Alaska

Walden Pond subdivision, Indiana

Installing vertical ground loop

Beaumont retirement community, Pennsylvania

from our national hotline. They purchase our experience, adapt our billboards, our publication ads, our brochures. It's a program that's ready to go."

In Lester, Pennsylvania, HEATAC Systems is the country's first metered space-conditioning service using GSHPs in commercial applications. "We have a track record now," says Ron Robertson, the general manager of HEATAC. "We've put installations in retirement villages, elder-care facilities, medical buildings, low-rise office buildings, schools, a fast-food restaurant, and a condominium complex."

HEATAC incurs the cost of installing, operating, and maintaining the equipment, typically on a 20-year contract, and charges the building operator for space heating, cooling, and water heating by measuring Btu consumption. Robertson claims that the cost of service is usually lower than the costs of alternatives, and he says that customers may purchase their systems at any time at a predetermined price. HEATAC is exploring ways to franchise its business to utilities or provide marketing services in trade for financing.

Nancy Wolf is the National Rural Electric Cooperative Association's GSHP marketing guru. Stationed in Denver, she travels the country helping the 970 members learn how best to promote ground-source technology. As liaison between manufacturers, distributors, and cooperatives, she coordinates contractor training workshops, installation field days, and utility employee workshops. So far, over 100 cooperatives in 21 states have been so impressed with potential savings that they've installed ground-source systems in their own buildings.

Formed in 1987 as an extension of the Technology School of Oklahoma State University, the International Ground Source Heat Pump Association (IGSHPA) offers a variety of promotional and educational tools in its GS System program. IGSHPA members have access to two- and three-day workshops, training videos and manuals, software for sizing ground loops, and case studies. In addition, the association helps members prepare news releases, print advertisements, and even television commercials—as well as providing graphics and masters for promotional brochures.

"What we're doing," says James Bose, executive director of IGSHPA, "is publicizing the notion of ground-source zones of opportunity, locations that have high energy costs—where demand has become a problem, or wood burning is increasing pollution, or there's no low-cost source of natural gas—and then providing answers to questions about the lowest-cost way to install ground-source systems.

"Texas is a hotbed; Louisiana and Oklahoma are good; Missouri is growing like mad; New York further north, Indiana, Ohio and Illinois, Oregon and Washington out west . . . ; Idaho has an income tax credit that almost pays for ground-loop installation."

What the future holds

About prospects for the future, EPRI's Powell Joyner says this: "About 25,000 to 40,000 GSHPs are installed per year, compared with 800,000 to 900,000 air-source heat pumps. The market is small but fast-growing, entrepreneurial. It is a utility-driven market. Residential units—the bulk of the market—are split between new, replacement, and add-on systems. The most dramatic movement in reducing costs has been mass installation of loops before the buildings go up, as at Walden Pond. Ongoing research is developing even higher efficiency GSHP equipment for introduction to the market in the future."

Applications in commercial settings are growing rapidly as architects and engineers become more familiar with system benefits. But as Joyner points out, GSHPs are still relative newcomers to the marketplace: "With air-source units, you can just walk your fingers through the Yellow Pages and call a dealer. With ground-source units, you have to customize the configuration of the loops. But ground-source technology is the best way to reduce peak loads, give the user high efficiency, and get rid of that unsightly outdoor unit or commercial cooling tower. GSHPs are growing fastest in the middle states, but they have a huge potential in the North. As the technology really cracks that market, you're going to see tremendous benefits for utilities and customers alike." ■

Want to learn more about how to promote ground-source heat pumps? These contacts may prove useful:

HEATAC Systems, Lester, Pennsylvania: Ron Robertson, general manager, (215) 595-1050

International Ground Source Heat Pump Association, Stillwater, Oklahoma: Teresa Tackett, director, (405) 744-5175

National Rural Electric Cooperative Association, Denver, Colorado: Nancy Wolf, consultant, (303) 388-0935

PSI Energy, Plainfield, Indiana: Nancy Miller, manager of direct marketing and sales, (317) 838-2568; national hotline, (800) 838-2568

Further reading

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This article was written by Michael Scofield, science writer. Background information was provided by Powell Joyner, Customer Systems Division.

TECH TRANSFER NEWS

Lightning Tracking System Commercialized

The satellite-linked National Lightning Detection Network (NLDN), developed by EPRI for virtual real-time tracking of lightning storms, is fast becoming a hit with users—even before its utility research mission is completed. A recent agreement with GeoMet Data Services, Inc., a subsidiary of Dynatech Corporation, makes the NLDN commercially available to users in other industries who are willing to invest about $10,000 for the equipment, satellite dish, and software required to access and use the lightning data. By constantly monitoring the signals from about 120 special sensors around the country, the system can locate lightning strikes and display their geographic locations on a computer monitor within about 8 seconds of an actual event anywhere in the United States.

Lightning strikes are typically detected by several sensors simultaneously. Each sends a signal to a satellite, which returns the signals to the NLDN control center, now located at the State University of New York in Albany. University researchers developed the Thunder software—available to network users—that processes and displays the data. GeoMet Data Services now operates the network and will relocate the control center to Tucson, Arizona, when a new facility is completed next year. The change in ownership and operation should be largely unnoticeable to present users. Another Dynatech subsidiary, Lightning Detection and Location Protection, Inc., manufactures the network sensors.

EPRI originally sponsored the development of the network on behalf of utility members in order to gather long-term lightning data to help better protect utility facilities and equipment from strikes, which cause between $50 million and $100 million a year in damage. But as utilities began using the network and word of its capability spread, university researchers and government agencies asked to join, according to William Shula, a senior technical adviser in EPRI's Electrical Systems Division.

The National Weather Service is looking into how it could use the data to improve general forecasting capability, and the U.S. Strategic Air Command is interested in joining the network. The data could prove useful in improving forecasts of wind shear at airports. Meanwhile, EPRI will continue to receive network lightning data for utility research purposes through the year 2002.

Among the earliest commercial users of the lightning network is American Airlines, which has been able to reroute aircraft around storm cells and defer landings at airports during storms thanks to the network's ability to continuously track lightning activity.

The real-time aspect of the network also appears to be of high value to utilities that use it. Like many of the 40-plus utilities on the network, Houston Lighting & Power routinely uses the data, along with color radar, to dispatch storm damage repair crews. HL&P figures it saved $15,000 in overtime costs during one storm alone.

Among other utility users, Duke Power no longer has to purchase commercial weather data because the lightning network fills the bill. Kansas City Power & Light uses the historical network data to determine whether equipment failure is lightning-related. Georgia Power cross-checks line outages against lightning data to target for inspection those that are related. Union Electric uses the data to determine when to allow crews to start work after a storm has passed. "We expect to hear of a growing number of similar applications in the future," says Shula.

For information about the NLDN, contact GeoMet Data Services, (602) 573-0090. ■ *EPRI Contact: William Shula, (415) 855-2303*

Refrigeration Guide Helps Target Incentives

Supermarkets account for 4% of all the energy used in the United States annually, with most of the electricity component of that consumption going to run refrigeration systems. High-efficiency refrigeration systems could greatly reduce commercial energy use, with benefits for supermarkets and utilities alike. But the diversity of systems, components, features, and energy-saving potential of various possible configurations of refrigeration equipment can make comparative evaluations difficult.

As part of an active conservation program aimed at reducing its need for generating capacity in the 1990s, New England Power Service Company was considering establishing incentives for supermarkets to install new, efficient refrigeration systems. NEPSCO needed accurate information about the demand and energy savings it could expect from the various systems, as well as dollar-value estimates of potential savings for both the supermarkets and the utility.

After surveying most of the supermarket customers to identify common configurations of refrigeration equipment, a NEPSCO project team used EPRI's *Guide for the Selection of Supermarket Refrigeration Systems* (CU-6740) and the EPRI Supermarket Energy Use and Demand Model to estimate potential savings for new installations and major retrofits under a variety of possible configurations. For each configuration utility analysts calculated performance results, annual electricity costs, energy savings, payback periods (with and without utility incentive offerings), and adjusted demand reduction.

NEPSCO's analysis using the EPRI guide and validated supermarket demand model indicated that the most beneficial features of new, efficient refrigeration systems were low pressure head through evaporative condensing or improved air-cooled condensing; external liquid-suction heat exchangers for low-temperature refrigeration; and hot-gas defrost. Because two of the identified features already showed favorable payback periods without utility incentives, NEPSCO chose to focus its incentives on the other two—evaporative condensing and external liquid-suction heat exchangers.

NEPSCO estimates that if all the supermarkets in its service territory install the recommended high-efficiency equipment, electricity demand for refrigeration will be reduced by more than 3.6 MW over the next 10 years, saving more than 31,000 MWh annually through the year 2000. Not only would such savings mean reduced operating costs for supermarket owners, but such a move could save NEPSCO an estimated $13.5 million in generating costs at current rates.

Similar results have been estimated by other utilities using the data and model. Commonwealth Electric Company figured that cost-effective retrofits of efficient supermarket refrigeration systems in its service area in Massachusetts could save over 15,000 MWh a year, or 27% of the energy currently used for that purpose. In New York, Empire State Electric Energy Research Corporation pegged the potential reduction in supermarket energy use statewide at 42%; it also estimated a 24% reduction in demand for power for supermarket refrigeration.

"The EPRI guide and software enabled us to design effective incentives by precisely quantifying the energy savings

available from various refrigeration equipment options," says NEPSCO's Robert O'Brien. "We could target incentive dollars where they were able to produce the greatest benefit." Adds Mukesh Khattar, a project manager in EPRI's Customer Systems Division, "The state-of-the-art technologies identified in recent EPRI studies will yield comparable savings to utilities and their commercial customers even when the refrigeration industry replaces chlorofluorocarbon refrigerants because of concern over damage to the earth's ozone layer." ■ *EPRI Contact: Mukesh Khattar, (415) 855-2699*

Utilities Get Help With PCB Management

The results of EPRI-sponsored testing have prompted the Environmental Protection Agency to ease its requirements for the reclassification of utility equipment, such as transformers, that may be contaminated with polychlorinated biphenyls (PCBs).

Utilities are replacing many transformers that have PCB levels of 50 parts per million (ppm) and higher in the insulating oil. Under EPA rules, units with PCB levels of up to 500 ppm (and sometimes higher) can be reclassified as non-PCB equipment, but these rules require oil sampling under conditions that can be difficult to meet and that could pose a hazard to utility personnel. EPRI-sponsored tests have shown that a single fluid exchange in draining and cleaning a transformer will always reduce the PCB level from 500 ppm to below the regulatory limit for reclassification, regardless of whether the sampling conditions for operating time and temperature have been met.

Utilities have begun using the EPRI results to significantly decrease transformer operating costs by obtaining from the EPA individual exemptions to sampling and monitoring requirements. With fluid replacement under the new technique accepted by regulators as a viable option, utilities can avoid the cost of early replacement of PCB-contaminated transformers. Baltimore Gas & Electric pioneered the use of EPRI's data in convincing the EPA to waive certain requirements and reclassify some 200 of its pole-type transformers (rated up to 25 kVA) that it would otherwise have had to remove from service because of PCB contamination. BG&E estimates that it will save $351,000 over five years in avoided replacement costs.

Similarly, Central Louisiana Electric, facing an estimated cost of $1.2 million to detoxify the oil in some 145 pieces of mostly pad-mounted power equipment, used EPRI's results to show that PCB levels would never exceed regulatory limits and that operation of the equipment for three months at 50°C (120°F) was not necessary. The utility figures that the EPA waiver of the 50°C clause is saving it $800,000 in detoxification costs. ■ *EPRI Contact: Gil Addis, (415) 855-2286*

Residential Program

Radiant Barriers

by John Kesselring, Customer Systems Division

ABSTRACT *By the late 1980s, tests in southern U.S. climates indicated that radiant barrier (RB) technology could effectively reduce air conditioning loads and thereby conserve energy. Although electric utilities, regulatory agencies, research organizations, and the general public showed increased interest in RB systems, several questions remained about system performance and about the efficiency of RBs in other U.S. climate zones. In the past two years, EPRI has published research results that answer many of those questions. As this research confirmed, installation of RBs can be cost-effective in some southern locations, but other options—such as increasing attic insulation—should be taken into consideration before making a decision.*

On clear, sunny days, the roof of a house absorbs solar energy. Absorbed heat moves through the roof by thermal conduction (heat transfer from molecule to molecule) and within the attic space by thermal convection (heat transfer due to bulk movements of the air). Attic ventilation normally dissipates some of this heat. However, the roof also radiates some heat directly into attic floor insulation. Radiant barriers (RBs) can significantly reduce thermal radiation heat transfer between the bottom of a roof deck and the top of the attic insulation. Because this, in turn, reduces heat transfer into the living space and thereby reduces cooling load, and because RBs might reduce heat loss from living spaces into attics in cold weather, utilities have expressed interest in the potential of RBs to reduce radiant heat transfer.

All materials emit energy by thermal radiation. The amount of energy given off depends on the surface temperature and the emissivity of the material. The higher the emissivity, the greater the emitted radiation. Emissivity is closely related to reflectance, a measure of how much energy is reflected by a material. A material with a high reflectance has a low emissivity, and vice versa. The reflective and nonradiating properties of an RB, which enable it to block radiant energy transfer, depend on the low emissivity and high reflectance of the RB's surface. In practice, RBs consist of thin aluminum foil bonded to kraft paper, polypropylene, or plastic films. An aluminum surface with an emissivity of 0.05 will block radiant energy transfer by reflecting 95% of the incoming energy and by radiating (emitting) only 5% as much energy as a perfect radiator would.

RB technology is simple, and excellent products are available from several manufacturers. RBs are usually installed in attics in one of two configurations: the barrier may be installed horizontally—that is, on top of conventional insulation—or it may be suspended from attic rafters (Figure 1). With the horizontal configuration, on a sunny day the energy emanating from the bottom of the roof decking into the attic space is reflected away from the attic insulation and prevented from entering the living space. With the rafter-mounted, or truss, configuration, on a sunny day the energy from the roof is prevented from entering the attic space because the RB's low-emissivity aluminum surface is a poor radiator.

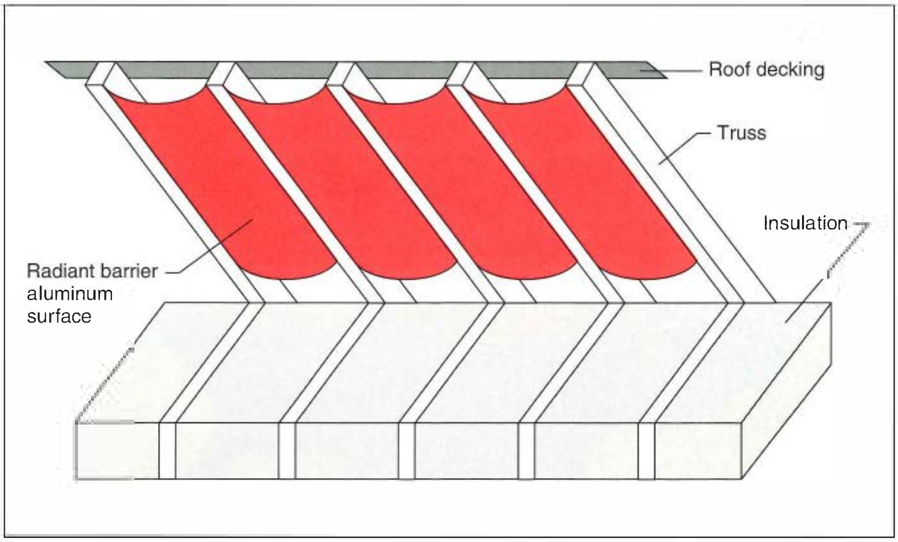
At present, there is no standardized method for testing the effectiveness of RBs in reducing heating and cooling costs. But studies by several organizations, including EPRI, have evaluated RB systems in southern U.S. climates and found that the systems can reduce summer ceiling heat gains there by about 40%. Since only a fraction of the air conditioning load in summer is due to heat gain through the ceiling, a home's total cooling load is lowered by a lesser amount. In the end, annual utility bill savings achievable with RBs in southern climates can be reasonably estimated to range from 2% to 10%.

Research objectives

On the basis of the results of limited testing in the southern United States, RBs were marketed aggressively in all sections of the country. To ensure proper and cost-effective use of this new technology, utilities needed detailed information on RB performance and effectiveness. In 1988 Oak Ridge National Laboratory (ORNL), the Tennessee Valley Authority (TVA), and EPRI held a symposium in which speakers from the research, utility, academic, and manufacturing communities reviewed the state of the art in RB technology as the first step in determining where RBs can be applied and how effective they can be. In a follow-on workshop sponsored by the same organizations, participants identified research needs and priorities.

Symposium speakers confirmed that RBs can reduce radiant energy transfer and air conditioning costs. The effectiveness of RBs in northern climates remained uncertain, however, as did the effects of dust, moisture, and attic ventilation on system performance. Further, basic questions remained regarding the most energy-efficient installation configuration (horizontal or truss) and the appropriate way to determine performance standards for RB systems. After dividing into three working groups to discuss installation and economic issues, field and laboratory testing, and materials research and standards, the workshop participants recommended a set of research topics. In accordance with those recommendations, EPRI subsequently supported research to evaluate the effects of moisture accumulation, dust, and attic ventilation on RB performance and to evaluate potential energy and demand impacts in several U.S. cities.

Figure 1 Rafter-mounted, or truss, configuration for an attic radiant barrier, which reduces heat transfer into the living space. In a new building, the radiant barrier may be draped over the rafter tops before the roof deck is applied.



Moisture accumulation

Previous testing conducted by ORNL at three unoccupied Tennessee houses used for research had shown that horizontal RBs (HRBs) reduced house cooling and heating loads more effectively than did truss RBs (TRBs). However, moisture condensation, which had been noted under a nonperforated HRB in a winter test, posed a potential problem, since it could stain ceilings and possibly lead to structural damage.

With support from the Department of Energy (DOE), TVA, the Reflective Insulation Manufacturers Association (RIMA), and EPRI (RP2034-24), ORNL undertook a study of attic moisture accumulation during the winter. The researchers placed perforated HRBs on top of the R-19 attic insulation used in the three research houses. One house was kept at a relative humidity of 55%; the other two, at 45%. Moisture levels in the attics were monitored both visually and with data-logging instrumentation.

ORNL found that moisture levels went through a daily cycle. While condensation formed on the RB undersurfaces at temperatures below 35°F, and condensation was heavier at 55% than 45% relative humidity, the moisture in all three houses generally evaporated during the warmer, afternoon hours. If temperatures remained below freezing, some condensation remained throughout the day. ORNL concluded, however, that the condensation on a perforated HRB during a typical Tennessee winter appeared to pose no structural problems or problems of wet insulation or stained ceilings.

Although these results, presented in EPRI report CU-6495, gave some assurance that moisture problems will not be created with perforated HRBs in climates that are no more severe than Tennessee's, moisture problems might arise in more severe winter climates. A full assessment of moisture problems in cold climates can be obtained only from field data, but much can be learned from modeling.

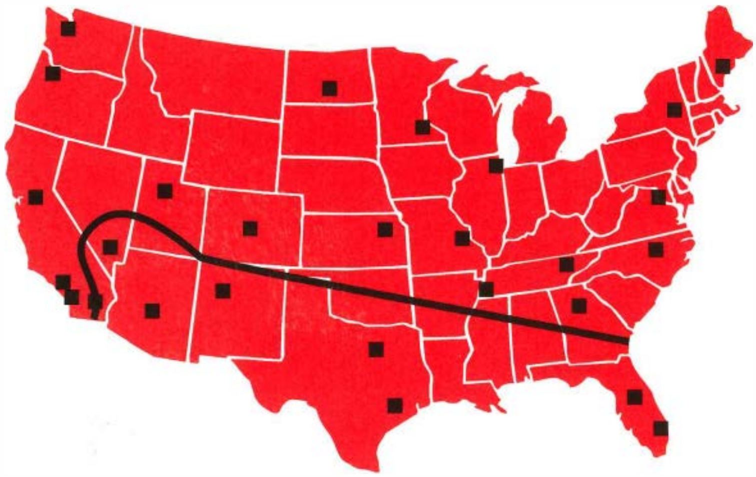
To make it possible to predict moisture accumulation under HRBs, ORNL modified a model for the thermal performance of attics containing RBs (RP2034-30; CU-7472). After partially validating the model by comparing its predictions with observations at the test homes, ORNL used it to perform parametric studies of moisture accumulation under a range of climatic conditions. ORNL found that the potential for moisture problems increases throughout most of the United States if the RBs and the various ceiling layers have low permeability.

Dust and ventilation effects

Dust increases the emissivity of a radiant surface, and when the dust layer becomes thick enough, the surface emissivity becomes that of dust. Some tests showed that even a little dust could raise HRB emissivity significantly, while other tests suggested that large concentrations might not significantly affect overall heat transfer. In addition, researchers realized that the type and amount of attic ventilation could critically affect RB performance and customer savings. Although the use of soffit, gable, and ridge vents in various combinations provides a range of ventilation levels, the best type and amount of ventilation were not known.

As part of RP2034-24—and again with support from EPRI, DOE, TVA, and RIMA—ORNL

Figure 2 Modeling results for 27 cities were used to project where radiant barriers can be cost-effectively applied. South of the black line, clean horizontal RBs costing 15¢ a square foot are cost-effective in houses that have ceiling insulation rated R-19 or less. (North of the line, such RBs are cost-effective in houses with insulation rated R-11 or less, but higher-rated insulation is typically used in colder climates.) Given higher RB costs, insulation levels above R-19, or a truss rather than a horizontal configuration, the area of cost-effective application shrinks to a smaller southern band.



used experiments at the three research houses in Tennessee to explore the impact of dust loading, attic ventilation area ratio (AVR), and ventilation type on RB performance. (AVR is the ratio of the total area of attic vents to the area of the attic floor.) To investigate the effects of dust loading, perforated HRBs were installed in two houses, and tests were run with no dust on the surfaces and with light and heavy dust loadings. To investigate the effects of AVR and ventilation type, unperforated TRBs and perforated HRBs were installed and tested with various combinations of ridge/soffit and gable/soffit vents. Attic heat flow and total house cooling were measured for all test conditions. The results are presented in CU-6817.

The dust-loading tests showed that although dust degrades the performance of an HRB, a home with R-19 attic insulation and a dusty HRB still has a lower cooling load than comparable homes without HRBs. Clean (and even slightly dusty) HRBs appeared to outperform TRBs, but long-term dust buildup could cause the performance of HRBs to fall below that of TRBs. In view of these results, ASTM standard C1158-90, issued in February 1991, recommends the use of the truss configuration in order to avoid the settling of dust on RB surfaces.

The study also found that under Tennessee summer conditions, there was no substantial difference in attic heat flow reduction for AVRs of 1:300 and 1:150 with either HRBs or TRBs. Further, with either ridge/soffit or gable/soffit vents, TRBs showed cooling load reductions of about 9% at an AVR of 1:150.

Performance in different climates

In a 1988 project for the Sacramento Municipal Utility District, Davis Energy Group (DEG) evaluated RB performance by means of a computer program that simulates hourly building energy performance for a full year. DEG calibrated the simulation program by using ORNL test data. Later DEG simulated RB performance in Miami as well. The researchers found that whereas for Sacramento the projected percentage annual energy savings were typically almost twice the percentage demand savings, for Miami the projected energy and demand savings were nearly equal. The differences appeared to be largely attributable to the greater coincidence of cooling loads and daylight hours in hot, dry climates (like Sacramento's) than in humid climates (like Miami's).

DEG's findings suggested that the value of RBs to utilities might vary significantly with climate, since demand savings are typically more valuable to utilities than energy savings. Hence EPRI sponsored a project (RP2034-36; CU-7220) in which DEG evaluated the potential energy and demand impacts of RB use in Abilene (Texas), Knoxville, Las Vegas, Miami, Minneapolis, and Portland (Oregon). While most other RB research had based projections on test data from the southeastern United States, this study modeled a range of climates on the basis of data from Nevada Power Company test houses in Las Vegas.

After improving its simulation model, DEG calibrated it by using the Las Vegas data and completed parametric runs with the model for three building types in each city. For each building type, runs were done for three levels of ceiling insulation, with and without attic ductwork. (Roof applications of RBs, by lowering air temperatures within attic spaces, can reduce the heat gain to air conditioning ducts running through the spaces and increase the efficiency of air conditioning systems.) Because of the potential for performance degradation from dust buildup, DEG did not include HRBs in the study.

The simulations indicated that TRBs could reduce seasonal residential cooling loads in all six locations. The greatest savings could be achieved in houses in the warmest locations, with the lowest ceiling insulation levels, and with attic ductwork. DEG also found that TRBs should increase average cooling-system efficiencies: by reducing daytime cooling loads and slightly shifting loads to nondaylight hours, RBs can lower average system condensing temperatures. The projected efficiency improvements were greatest in climates with high daily temperature ranges.

DEG's simulations suggested that RBs could reduce annual heating loads slightly in the six cities. The projected heating savings were highest in Minneapolis and Portland. Since heating and cooling costs can also be reduced by increasing the amount of conventional attic insulation or by using more-efficient equipment, however, the installation of RBs may not be the most cost-effective way to increase heating and cooling energy efficiency.

Independently of DEG's effort, ORNL projected cooling and heating load factors for

HRBs in 27 cities (RP2034-30; CU-7472). On the basis of those projections, which are consistent with DEG's, ORNL prepared a map showing where clean HRBs can be cost-effective if the barriers cost no more than 15¢ per square foot and are installed in homes that already have ceiling insulation rated R-19 or less (Figure 2). Under other conditions—if RB costs are higher, if insulation rating exceeds R-19, if ceiling permeability is low, or if TRBs are used (as recommended by the ASTM)—the area in which RBs are cost-effective shrinks; ultimately it is reduced to parts of Georgia and states on the southern U.S. border.

In addition to benefiting consumers by reducing energy costs, RBs may also benefit utilities by reducing electricity use during peak periods. Most of the savings projected by DEG would occur between 10 a.m. and 6 p.m., concurrent with utility peak loads in summer. DEG's simulations indicated that in locations with 24-hour cooling loads, RBs would reduce energy use in daylight hours and increase energy use slightly at night.

Nuclear Power Plant Equipment

Capping Off a Decade of Qualification Research

by George Sliter, Nuclear Power Division

ABSTRACT *The qualification of safety-related equipment was among the most important issues in nuclear power safety during the past decade. In close collaboration with utility advisers, EPRI's research program provided technical assistance for meeting mounting regulatory requirements at minimum cost. Now that qualification by testing and analysis has been established and the Nuclear Regulatory Commission has completed extensive audits of equipment in operating plants, EPRI is capping its research in this area with a comprehensive reference manual and training materials that will help utilities preserve the qualified status of equipment over the lifetime of their plants.*

The qualification of safety-related equipment in nuclear power plants, mainly by testing, ensures that equipment will perform its safety function during design-basis pipe-rupture accidents and earthquakes, even after years of operation. To simulate aging under operating conditions, a specimen is (1) baked at an elevated temperature for a period calculated to produce the same degradation that would occur at its service temperature over its installed life, and (2) subjected to the radiation dose it would experience over its installed life. The age-conditioned specimen next undergoes a simulated accident radiation dose. Finally, the specimen is operated while being subjected to simulated earthquake motion on a shake table and then to high-pressure steam in a test chamber (Figure 1). This proof-testing process is sometimes referred to as "shake and bake."

During the 1960s and 1970s, the technology and procedures to perform these complex simulations were evolving at the same time that standards and regulations were being formulated. Plant owners, who bear the responsibility for qualification, found themselves in a catch-up mode. In the late 1970s, the Nuclear Regulatory Commission (NRC) began an intensive evaluation of equipment qualification (EQ) programs at operating plants. At the same time, EPRI member utilities endorsed the initiation of an equipment qualification research program (RP1707). The program was to provide technical and procedural assistance to utilities, helping them meet qualification standards and regulations with state-of-the-art methods and at minimum cost.

After a dozen years, expenditures of some $10 million, and delivery of more than two dozen research products, EPRI has successfully completed its EQ research. (The Institute will, of course, continue to track emerging issues.) The Equipment Qualification Advisory Group, composed of representatives of all EPRI member nuclear utilities, has documented cost savings of at least $152 million as a result of EPRI's EQ program. Two recent products of the program, an equipment qualification reference manual and EQ training materials, will help maintain utility staff knowledge and awareness of EQ in the years to come.

Reference manual

Until now, descriptions of equipment qualification technology have been scattered in industry standards, NRC regulations, and various reports and papers. The EPRI EQ Reference Manual—scheduled to be issued this fall for trial use—gathers this information in one place.

As described in detail in the manual, the EQ process begins during plant design and continues throughout the plant's operating life (Figure 2). The first step in qualifying plant equipment is to perform a systems analysis to identify safety-related systems and components, the functions they must perform, and the period of time (from seconds to months) during which equipment subjected to accident conditions must operate.

The next step is to determine the normal, abnormal, and accident environmental conditions for safety-related equipment. The following types of conditions fall into the normal and abnormal categories: ambient temperature (including excursions because of such abnormal events as loss of off-site power), equipment self-heating, operational cycling, vibration, humidity, and background radiation. Equipment inside the reactor containment building, a harsh-environment area, could experience postulated accident conditions: steam heat (about 500°F), pressure (about 5 atmospheres), radiation (200 million rads), water spray chemical spray from emergency cooling systems, and mechanical loading. Any of these conditions could conceivably cause concurrent failures in redundant safety systems.

Most equipment outside the containment is remote from potential high-energy pipe breaks or high radiation from circulating fluids in pipes. This mild-environment equipment experiences no conditions more severe than operating conditions. The only event that could lead to common-cause failure of such equipment is an earthquake.

Harsh-environment equipment is usually qualified by so-called type tests: laboratory simulations of aging stressors, accidents, and earthquakes on a representative specimen. Because these tests use only one prototype, a margin of conservatism (typically 15%) is added to one or several of the simulated accident conditions. Mild-environment equipment can be qualified with less rigor using sound design for all service conditions, good quality assurance practices, and periodic surveillance, maintenance, and replacement.

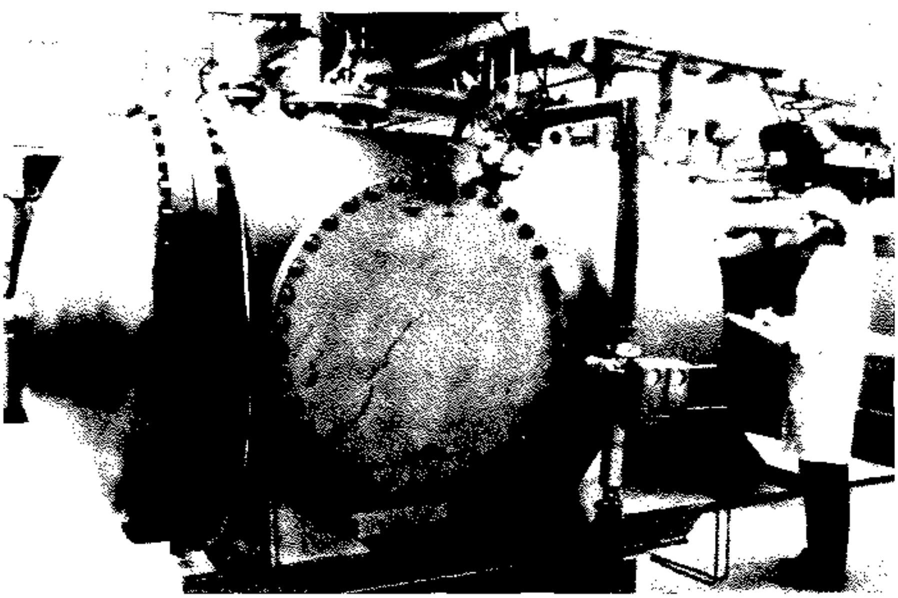


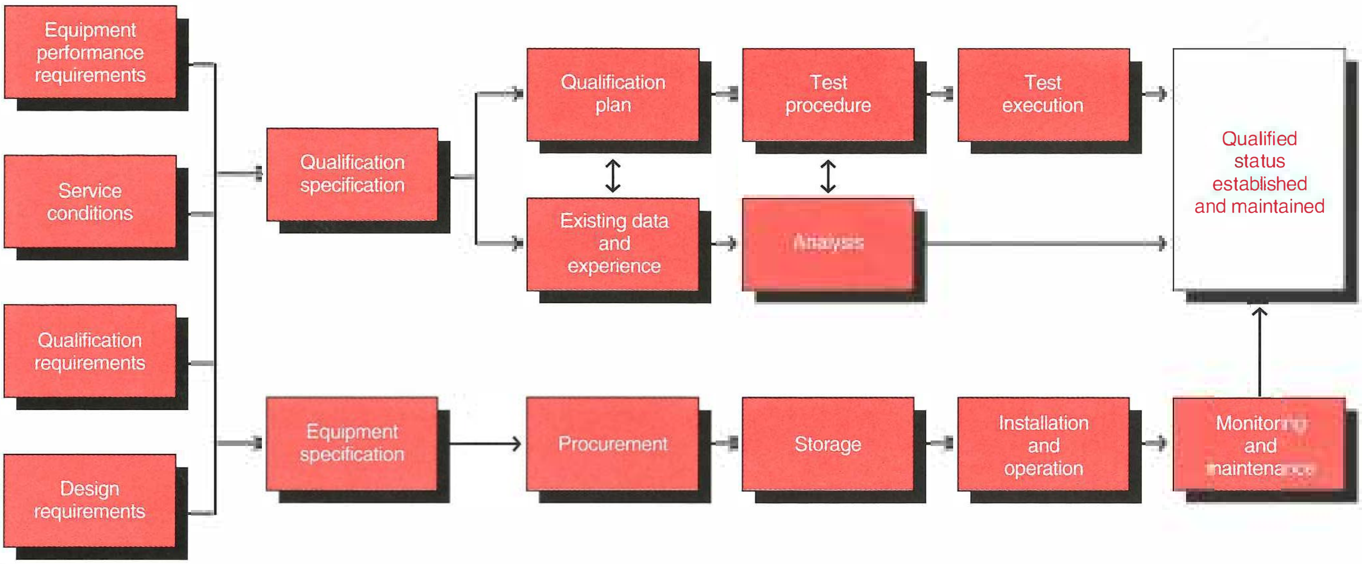
Figure 1 To prove that safety-related electrical equipment can operate under the high temperatures and pressures produced by the break of a main reactor coolant pipe in a nuclear power plant, a prototype first undergoes thermal, radiation, and operational cycling aging and then is tested under simulated loss-of-coolant accident conditions in a chamber like this. (Photo courtesy of the Acton test facility of NTS Inc.)

In addition to describing all the steps in the qualification process, the EQ Reference Manual discusses qualification of and operating experience with specific equipment types, such as cables, terminal blocks, motors, solenoids, transmitters, relays, switches, and batteries.

The manual also highlights the many products EPRI has developed to help utilities qualify equipment. Among these products are the following:

- A review of aging theory and technology that includes a compendium of aging data useful in applying the Arrhenius mathematical model of thermal aging, and that also points out the model's limitations. This 1981 report (NP-1558) has become an EQ bible.
- The Equipment Qualification Data Bank, a computerized, remotely accessible source of summary qualification data on some 10,000 items of electrical equipment in more than 90 operating plants. It also contains information on the aging properties of some 150 nonmetallic materials used in safety equipment. More than 66 subscribing plants use this database to avoid costly duplication of industry EQ efforts.
- Lubrication guides (NP-4735 and NP-4916) for the selection and maintenance of oils and greases exposed to radiation in nuclear plant equipment. Information about replacing lubricants and about the interim use of mixed greases has reduced at least one plant's forced-outage time.
- Full-scale hydrogen-burn tests (NP-2953). The results indicated that equipment qualified for design-basis accidents can generally function during and after several seconds of extremely high atmospheric temperatures (around 2000°F) resulting from the burning of hydrogen from degraded cores (as in the Three Mile Island accident).
- Methods for cost-effective qualification of active mechanical equipment (NP-3877). These can be used to qualify rugged pumps and valves without expensive item-by-item testing under simulated accident conditions. This effort helped convince the NRC that it

Figure 2 The process of establishing and maintaining the qualified status of safety-related equipment in a nuclear power plant begins with plant design and ends only when the plant ceases to operate. Qualification is established by testing, analysis, or a combination of the two approaches. Careful monitoring and maintenance of equipment are essential to preserving its qualified status throughout the plant's operating lifetime.



need not extend its rulemaking for environmental qualification of electrical equipment to mechanical equipment.

▫ A guide for monitoring equipment environments during plant operation (NP-7399). The guide recommends approaches for establishing a program or improving existing programs, citing the advantages, disadvantages, and approximate cost of a variety of methods and devices for tracking plant temperatures and radiation levels. When, as is typical, environments are found to be less severe than assumed for design and qualification, the lower measured values can be used to decrease the frequency of equipment and seal replacement (see NP-6731) and to support plant license renewal beyond the current 40-year term.

▫ A program to compare natural, in-plant aging with artificial aging (NP-4997). Since 1985, the program has tracked material property degradation in cables and devices placed in nine reactor containments and compared the results with the Arrhenius model predictions used to specify the duration of accelerated aging in qualification tests. Results from this long-term effort are expected to reduce the current uncertainty about accelerated-aging technology and provide information that will be useful for license renewal.

▫ The cable indenter aging monitor (NP-7348), a calibrated hand-held device that indents the surface of installed plant cables to evaluate their remaining useful life. The method mimics a troubleshooter's practice of pressing a fingernail into exposed cable insulation to gauge its brittleness. A favorable measurement could provide last-resort proof that a particular cable run need not be replaced.

The EQ Reference Manual also discusses seismic qualification using shake-table testing or experience from actual earthquakes to quantify ruggedness under earthquake motion. An EPRI study (NP-3326 and NP-5024) showed that aging degradation does not reduce the seismic resistance of most equipment types. Projects to specify generic equipment ruggedness spectra on the basis of existing test data and to provide methods for verifying the adequacy of equipment hold-down bolts began under RP1707; the projects are continuing under the Nuclear Power Division's Seismic Center.

After thoroughly covering the technical concepts and procedures of equipment qualification, the reference manual discusses the long and complex evolution of EQ standards and regulations. In its audits in the 1980s, the NRC cited industry deficiencies in meeting these complex regulations, especially in the area of documentation, and levied fines totaling several million dollars. The reference manual and the EQ training materials described below aim to facilitate compliance with EQ regulations in the future.

EQ training materials

Now that the NRC has verified that all safety-related equipment in operating plants is fully qualified, utilities need to preserve that qualified status during the remaining operating lifetime of their plants. This task may pose an even greater challenge than establishing qualification because it requires attention to procedural and documentation details by the several organizational units involved in the process. This challenge will grow as equipment ages, parts are replaced, components become obsolete, suppliers dwindle, and personnel with EQ skills are assigned to other plant activities (EPRI estimates that the yearly turnover of utility EQ personnel is 30%).

The NRC audits pointed out the general need to include the topic of equipment qualification directly in utility training programs (in contrast to the common practice of sending staff off-site to attend courses offered by EQ consultants). To help meet the challenge of maintaining qualification, EPRI has developed training materials—lesson plans, slides, and videotape—that utilities can integrate into their existing training programs. The course reflects more than a decade of EPRI EQ research, EQ training seminars (NSAC-58), and interactions with utility representatives from the Equipment Qualification Advisory Group.

The courseware consists of four modules tailored to the knowledge needs of engineers, managers, quality assurance/quality control staff, and maintenance staff, respectively. Each module follows the accepted industry practice for performance-based training courses, is technically generic (thereby providing a degree of EQ program uniformity across the industry), and can readily be modified by utility training departments to include plant-specific terminology and procedures. Lessons focus on the technical aspects of EQ, aging methods, spare part procurement, dedication of commercial-grade items for safety-related use, standards and regulations, the role of maintenance (with detailed examples), documentation requirements, shelf life in storage, and requirements for reporting noncompliance with regulations.

The many R&D products that have emerged from EPRI's equipment qualification program, especially the reference manual and training courseware, have benefited and will continue to benefit utilities by improving safety performance, reliability/availability, and regulatory compliance while controlling operating and maintenance costs. Continuing vigilance in this area can help ensure that the industry's large investment in equipment qualification pays off during the remaining license term of plants, including perhaps a license renewal term of 20 years.

Land and Water Quality

VALOR Code: A Flow Simulator

by Dave A. McIntosh, Environment Division

Considerable effort has recently been devoted to developing computer codes that can predict the movement of organic liquids in the subsurface. This interest stems from new regulations that address the health and environmental risks posed by leaks and spills of organic chemicals. These regulations restrict the land disposal of organic waste and, in some instances, ban the land disposal of organic substances outright.

Organics enter the subsurface environment primarily via leaks in pipes and storage tanks, infiltration at waste disposal facilities, and accidental spills (Figure 1). Consequently, utilities have an interest in developing a capability to predict the transport and fate of organic chemicals associated with coal tar sites, petroleum products, and organic solvents used at power plants. Many organic compounds emanating from these sources have low water solubility and migrate through the subsurface environment as a combination of free product and dissolved and gaseous phases.

ABSTRACT *Recent regulations restricting the land disposal of organic substances have intensified utilities' interest in learning more about the transport of these compounds. VALOR is a personal-computer-based code that simulates the flow of immiscible liquids through the subsurface environment. Simulation results presented in graphic or tabular form allow utilities to predict the movement of liquids leaked from storage tanks or migrating from coal tar disposal sites, and to select appropriate remediation measures.*

VALOR's capabilities

Regulatory developments, together with utilities' need to assess the consequences of their nonaqueous liquid leaks and spills, have spurred the development of the VALOR code (RP2879). Development began in 1988 after an extensive review of available codes that model the transport of immiscible liquids (EPRI report EA-5976). The review identified two categories of models: sharp-interface models and models that incorporate capillarity.

Though sharp-interface models require fewer input parameters than capillarity models do, they are fraught with simplifying assumptions that limit their general applicability. Conversely, models that treat capillarity require extensive input data, skilled users, and a large computational capacity. In developing VALOR,

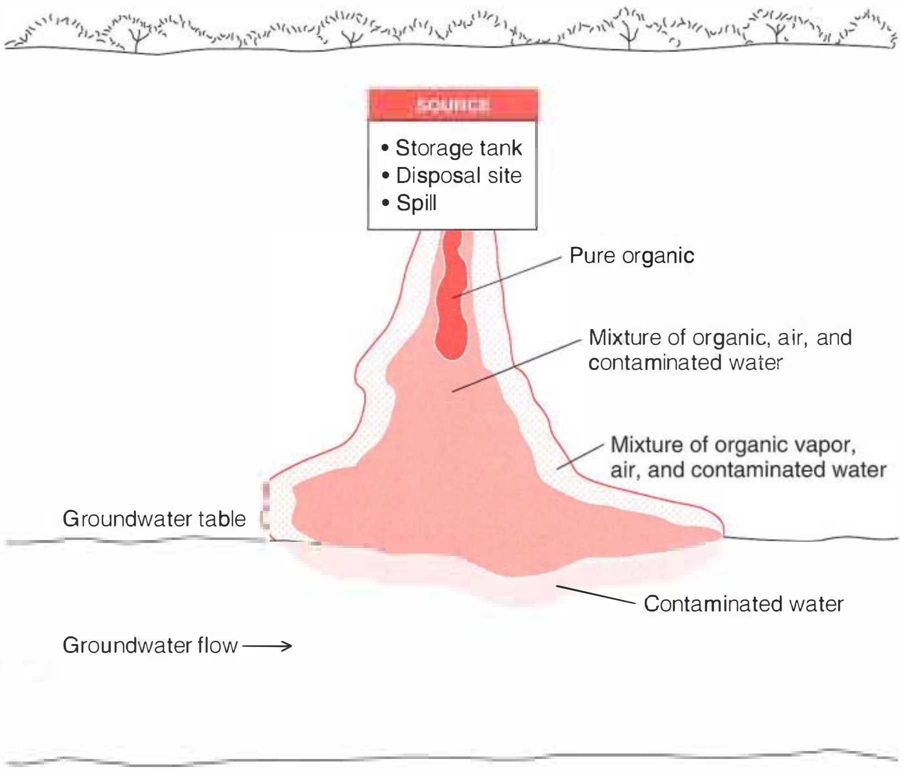


Figure 1 Organic compounds with low water solubility can migrate through the subsurface environment as a result of leaks in fuel oil and solvent storage tanks or transport from coal tar disposal sites. The VALOR code can simulate the migration of these immiscible liquids, determining their likely fate and helping utilities plan remedial action.

researchers at the University of Michigan adopted the most accurate, flexible, and robust modeling approach consistent with the computational capability of personal computers.

VALOR is a two-dimensional numerical code that simulates the unsteady flow of an immiscible liquid in the saturated or unsaturated subsurface. In simulating immiscible fluid migration, the code considers the simultaneous movement of water and air. Because it includes capillarity, VALOR can realistically represent plume spreading at the interface with ambient fluids.

VALOR is designed to handle two-dimensional flow problems and hence can treat, in a limited way, heterogeneous and anisotropic hydraulic conditions. It can simulate surface water recharge, finite-duration influx of an immiscible liquid, four soil strata, and the spreading of a lighter-than-water plume on the groundwater table.

To incorporate the effects of capillarity while retaining the ability to run the code on a personal computer, the researchers had to make a number of simplifying assumptions. Three of these simplifications can restrict model applicability:

- Biological and chemical transformations are negligible.
- Interphase mass transfer is minor.
- Capillary pressure and relative permeability are unique functions of fluid saturation.

The first two assumptions directly affect the mass balance computations. Moreover, chemical transformations and mass transfer can result in changes in the physical properties of the fluid phases. The third simplification disregards the fact that the relationship between capillary pressure, relative permeability, and fluid saturation may differ for soil-wetting and -draining conditions.

Using the model

To predict the movement of a spill or leak of immiscible liquid, the VALOR user must specify the initial condition of the subsurface and the hydraulic state at the boundaries. The user must define soil hydraulic characteristics and the physical properties of the transported fluid. Table 1 summarizes the input data requirements.

Table 1
VALOR INPUT DATA REQUIREMENTS

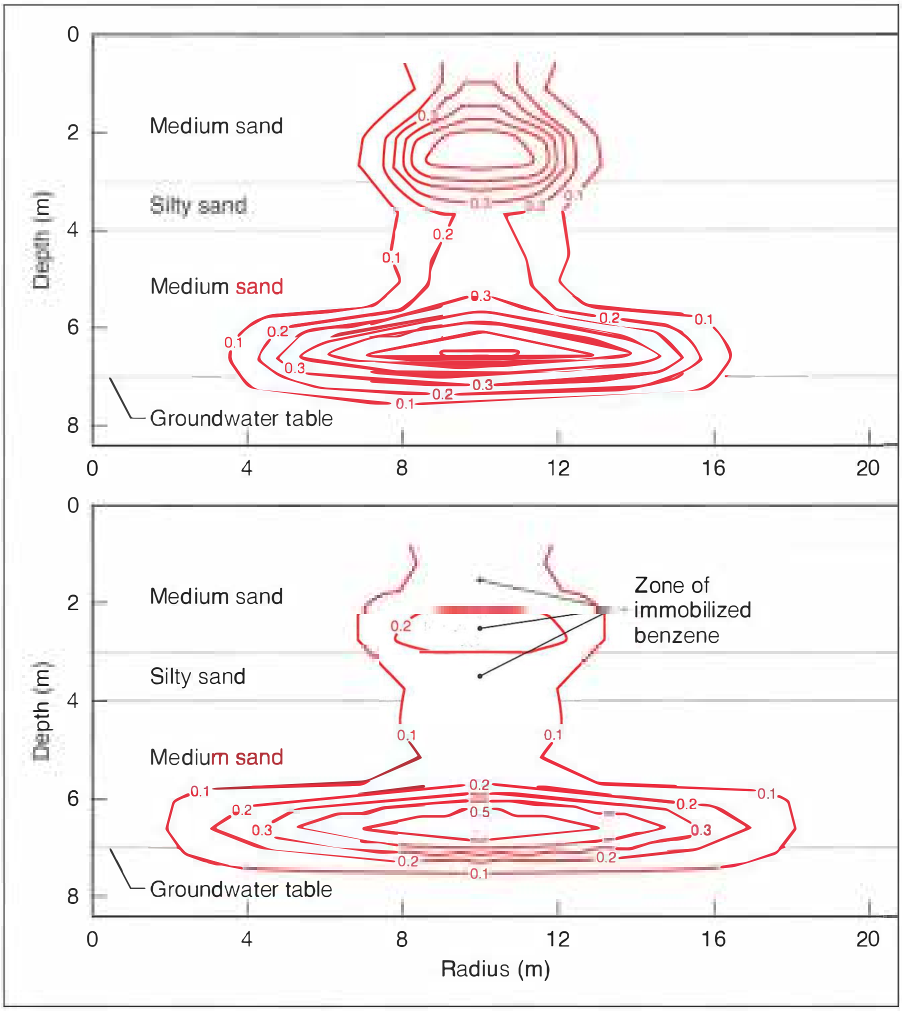
Data Type	Parameters
Properties of immiscible liquid	Density
	Viscosity
	Surface tension (air-organic and organic-water)
	Compressibility
System definition	Thickness of strata
	Depth to groundwater table
	Source location
	Rate and duration of leakage
	Surface water infiltration
Soil information	Porosity
	Saturated permeability
	Relationship of pressure, permeability, and saturation
	Residual saturation

Built into the code is the ability to help the user select appropriate values for the liquid and soil input parameters. VALOR also provides default values as a function of soil type. The output from the model includes an echo of the input parameters, a tabulation of the spatial distribution of the contaminant at each time step of the simulation, and contour plots of the spread of the contaminant plume at specific times.

VALOR's input/output interfaces guide users in developing and editing input data files and in reviewing and printing results. Options include data entry or editing, execution of the simulation model, examination or plotting of the model output, and on-line help. A mouse is used to select items from pull-down menus. For example, under the Data option, users can create new data files, retrieve and edit existing files, and print and save files.

The Execute option is used to perform the necessary computations with the input data

Figure 2 For a sample scenario involving a 30-day, 228-gallon-per-day leak of liquid benzene, VALOR shows the configuration of the benzene plume at 30 days and 60 days. The contours identify the fraction of pore space occupied by benzene. The rest of the pore space contains water and/or air. After 60 days, a portion of the benzene is immobilized in the upper layers, and the remainder of the plume has reached the groundwater table.



file. VALOR has a built-in check to ensure that all the required data have been specified. Selecting from the Output menu, users can view simulation results both graphically and in tabular form, either separately or together. By alternating between the raw data and the contour plots of the data, users can track contaminant infiltration and spreading. Enlargement of a contour plot to full-screen size is also possible.

Sample application

VALOR was used to simulate the impact of a 228-gallon-per-day leak of liquid benzene on the subsurface environment. According to the scenario, the leak lasted for 30 days and was then stopped. The groundwater table was assumed to lie 7 meters below the location of the leak, and the subsurface was represented by strata of medium and silty sand.

The simulation results (Figure 2) indicated that the layer of silty sand, less permeable than the medium sand, would retard the movement of benzene through the system. At 60 days (30 days after leak cessation), an immobilized fraction of benzene would remain in the upper layers. Incoming surface water recharge would later leach this residual benzene.

The VALOR code and its interfaces run on an IBM PC (AT or compatible) with 1 megabyte of random-access memory, 1 megabyte of extended memory, a math coprocessor, a color monitor, and a mouse (optional). The code will be released through the Electric Power Software Center by November 1991.

Commercial Program

Supermarket Air Conditioning and Dehumidification

by Mukesh Khattar, Customer Systems Division

Supermarkets are highly energy-intensive businesses, with energy costs that often exceed annual profits. The greatest share of supermarket energy costs is for refrigeration: display cases, coolers, and walk-ins refrigerated 24 hours a day typically account for more than half the electricity used in a store.

Supermarkets operate most efficiently when relative humidity is kept at 40–45%. At higher humidity levels, condensation develops on display case surfaces and doors, requiring the use of antisweat heaters. Excess humidity also causes frost buildup on refrigeration coils, which reduces energy efficiency by creating an insulating effect and by necessitating more frequent defrosting.

While frost buildup on refrigeration coils serves to reduce air moisture, it does so at high cost. Dehumidification using the air conditioning system is much more efficient. To remove a pound of moisture from the air, refrigerated cases for fresh food require 2 to 4 times more energy, and frozen-food cases 6 to 12 times more energy, than an air conditioning system.

Most commercial air conditioning systems are designed primarily to control temperature, however, and typically produce a relative humidity of approximately 55%. When forced to control humidity to a lower level, these systems must operate longer to remove moisture. In turn, the store air becomes too cool and must be reheated to a comfortable temperature. Moreover, moisture removal via overcooling often requires the use of larger equipment.

Alternatives to these conventional systems are available. High-efficiency electric air conditioning and dehumidification systems can reduce or even eliminate overcooling and reheating energy penalties. Gas-fired desiccant equipment combined with electric air conditioning is another option for effectively controlling humidity in supermarkets. But gas-fired desiccant equipment warms the air during moisture removal, adding to the heat that must be removed by the electric air conditioner.

EPRI has conducted a detailed analytical simulation study (RP2891-3) to determine the relative performance and cost-effectiveness of conventional supermarket electric air conditioning equipment, high-efficiency electric air conditioning/dehumidification equipment, and gas-fired desiccant dehumidification equipment. Researchers used a public-domain analysis tool to simulate the operation of a typical 40,000-ft² supermarket located in Miami, Florida. Miami's climate, with prolonged periods of high humidity, is representative of the humidity conditions found for shorter periods in many other U.S. locations.

Economic and performance comparisons for the air conditioning/dehumidification options included equipment size, installation cost, electric and gas energy requirements, and annual energy cost. Energy costs for refrigeration and other store end uses were also considered.

ABSTRACT *Commercially available high-efficiency electric air conditioning and dehumidification systems have been used successfully in many supermarkets. These systems can achieve the optimal humidity level for refrigerated display cases to operate efficiently, and they can often be installed and operated more cost-effectively than either gas-fired desiccant dehumidification systems or conventional electric equipment. With a lower in-store humidity level, supermarket owners can reduce overall energy costs and increase profit margins while improving product quality and customer comfort. Further energy cost savings can be achieved by incorporating cool storage technology and/or heat pipes into the high-efficiency electric systems.*

Conventional electric vs gas-fired desiccant

A conventional electric air conditioner is a single-path vapor-compression system that processes the humid outdoor air and the drier indoor return air together. All the air is channeled through a cooling coil to accomplish both temperature control and dehumidification. The temperature of the air leaving the cooling coil ranges from about 52° to 56°F; the airflow rate is typically 1.0 cfm/ft².

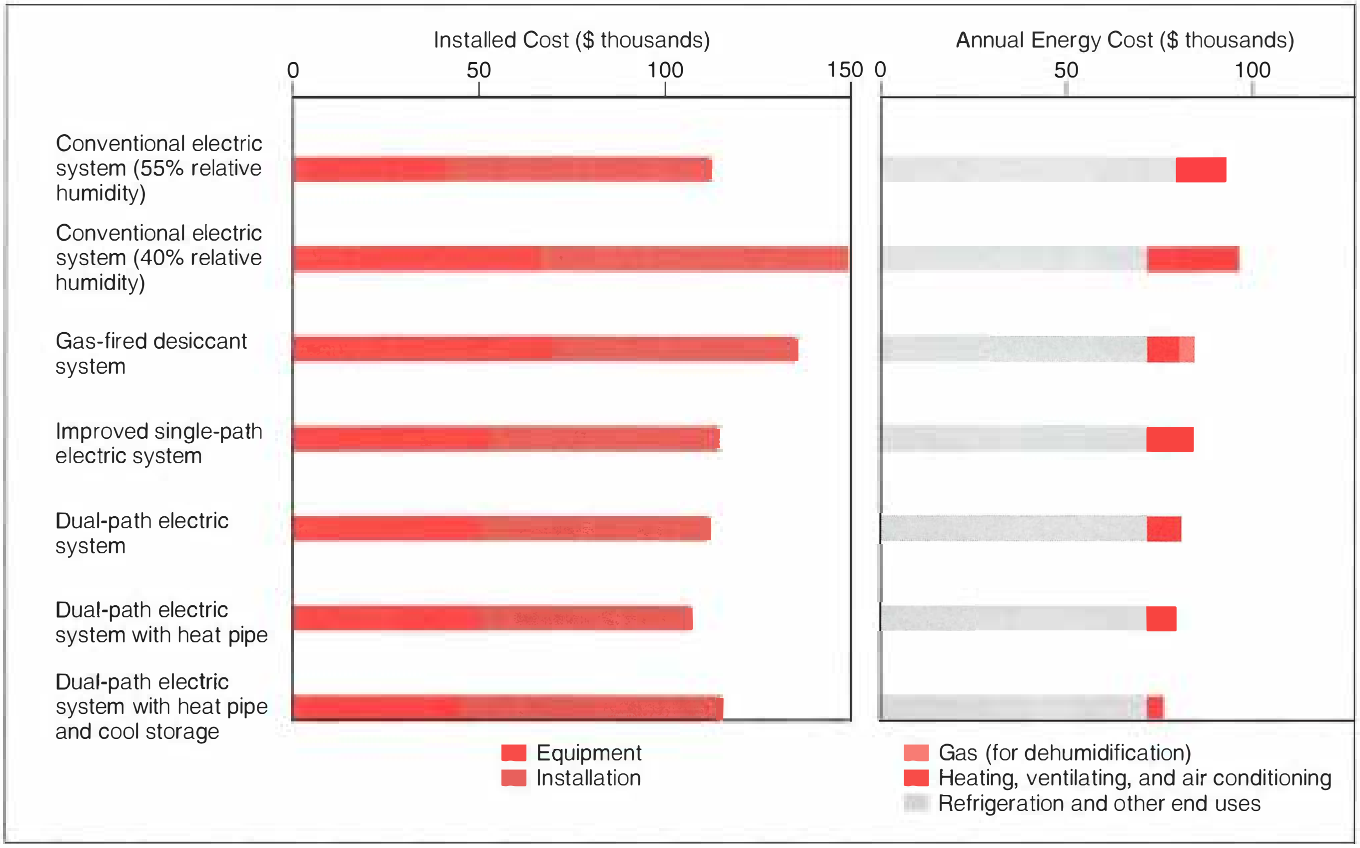
A hybrid gas/electric system uses a desiccant material to draw moisture from the humid outdoor air before the air enters the cooling system. The air heats up as moisture is adsorbed from it, and this warmed input air is then cooled to the desired temperature by an electric air conditioner. Following each round of adsorption, a gas-fired burner regenerates (drives the moisture from) the water-saturated desiccant to permit reuse of the material. The desiccant systems have airflow rates as low as 0.5 cfm/ft², reducing fan power accordingly.

The simulation showed that conventional electric air conditioning systems, which are primarily designed for temperature control in commercial buildings, do not perform well for humidity control. These systems therefore do not compare well with gas-fired desiccant systems in maintaining lower in-store humidity (Figure 1).

The study assumed flat-rate electric service costs of 4.69¢/kWh, plus $6.25/kW above 10 kW, and a gas cost of 50¢/therm. At these rates, the supermarket's total annual energy cost was 10% higher with a conventional electric air conditioner operating at 55% relative humidity (its normal design level) than with a gas-fired desiccant system operating at 40% relative humidity. Part of the higher total supermarket energy cost with the conventional air conditioner was due to the increased work required of the refrigeration system in order to remove moisture from the air.

The conventional system could achieve a

Figure 1 Cost results from EPRI's analytical simulation study of alternative air conditioning/dehumidification systems for a Miami supermarket. The left graph shows installed costs for the systems. The right graph shows annual energy costs for the systems as well as for other supermarket end uses. (The study assumed a relative humidity set point of 40% except in one case with the conventional electric equipment, as noted.) The results indicate that high-efficiency electric systems are more economical for supermarket space conditioning than either conventional electric equipment or gas-fired desiccant equipment.



40% humidity level if allowed to run for longer periods, but the resulting overcooled air would have to be reheated to maintain a comfortable in-store air temperature. This method of operation would also require larger equipment, contributing to higher installation and energy costs compared with the gas-fired desiccant system.

High-efficiency electric alternatives

Various configurations of high-efficiency all-electric air conditioning/dehumidification systems are available. All have some combination of low coil-leaving temperature, low airflow volume, and air bypass—that is, the ability to let the relatively dry air returning from the store bypass the cooling coil.

The key to a successful application is to match the dehumidification fraction—the ratio of the system's latent cooling (moisture removal) to total cooling capacity—with the dehumidification fraction of the cooling load. The cooling equipment size, airflow rate, coil-leaving temperature, air bypass, and controls can be adjusted to efficiently achieve the desired humidity and temperature.

The study examined both dual-path electric systems and improved single-path electric systems. A dual-path system (Figure 2) cools air to about 40–45°F to remove more moisture from it. The air is processed in two separate streams, with the humid outdoor air directed to a primary coil (for low-temperature cooling) and the relatively cool and dry return air directed to a secondary coil. The cooled and dehumidified air from the primary path is mixed with the warmer return air from the secondary path, thereby reducing the reheating energy requirement. The airflow rate can be reduced to 0.5 cfm/ft^2, as with the desiccant system. Two separate subsystems of coils and compressors are needed for this system, but the smaller air conditioning equipment components, smaller ducts, and reduced electrical wiring requirements serve to lower installed costs.

The improved single-path system also uses low-temperature cooling for dehumidification. It allows some of the return air to bypass the cooling coil for subsequent remixing before delivery to the store, providing reduced airflow volume over the coil. Like the dual-path system, this system allows downsizing of equipment components and reduction of ancillary costs.

In the simulation, both the improved single-path system and the dual-path system proved to be economically superior to the gas-fired desiccant equipment (Figure 1). At 40% relative humidity and with flat electricity rates, the improved single-path, dual-path, and gas-fired desiccant systems displayed similar energy costs, with the dual-path electric system slightly more economical to operate than the others. The gas-fired desiccant system had a much greater installed cost, making it the least competitive of the three systems.

Heat-pipe heat exchangers and cool storage systems

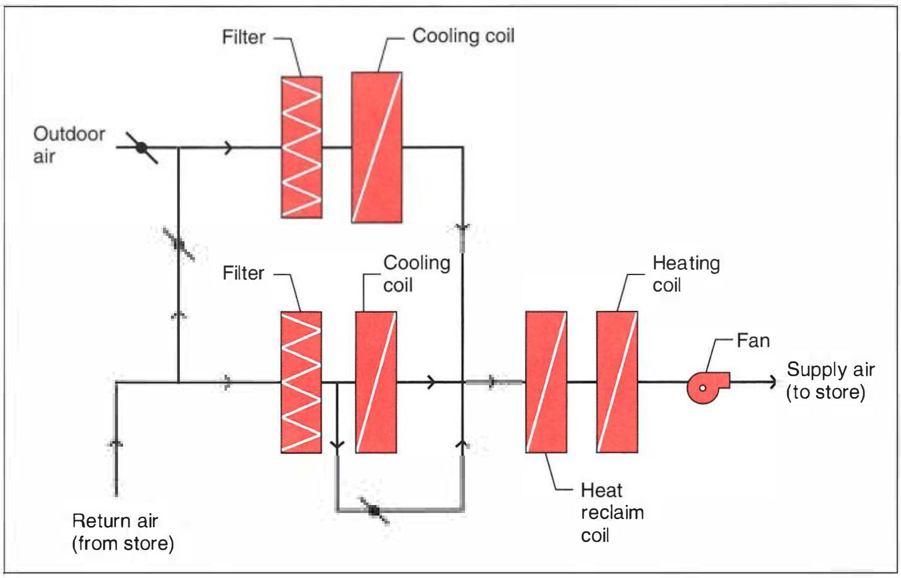
Heat pipe heat exchangers and cool storage systems are two important commercially available technologies that can be incorporated into dual-path and improved single-path electric systems to further improve efficiency.

A heat pipe heat exchanger reduces both the cooling and reheating energy requirements by transferring heat directly from the warm air entering the cooling coil to the low-temperature air leaving the coil (Figure 3). It enhances the dehumidification capabilities of both dual-path and improved single-path systems and, in some applications, enables the use of smaller air conditioning equipment. Increased fan power is needed to move air over a heat pipe heat exchanger, which may raise both the energy and installed costs. In a well-designed system, however, the reduced size of the air conditioning equipment and the lowered cooling and reheating costs should more than offset the increased fan power costs. A heat-pipe-assisted system should have minimal overall installed costs compared with systems without a heat pipe.

An ice storage system takes advantage of time-of-use rates to make ice during off-peak hours for use in on-peak space cooling. In EPRI's study, ice storage was simulated for both the dual-path and improved single-path electric systems, with and without heat pipe assistance. The simulation assumed a stand-alone cool storage installation—that is, no integration with any elements of the store's refrigeration system. Time-of-use rates applied in the study were as follows: 4.064¢/kWh off-peak and 6.489¢/kWh (plus $6.25/kW over 10 kW) on-peak.

A dual-path system equipped with both a heat pipe and a cool storage system and operated to take advantage of time-of-use rates had the lowest energy cost of all the systems simulated in the study (Figure 1). The simulation indicated a payback period of only about two years for the cool storage enhancements.

Figure 2 Dual-path electric air conditioning/dehumidification system. This system processes the air in two streams: the humid outdoor air is directed to a primary coil for low-temperature cooling and dehumidification, while the relatively cool and dry air returning from the store is directed to a secondary cooling coil. Bypass features allow the return air to be routed around the secondary coil or allow a portion of it to be diverted to the primary coil, as cooling or dehumidification needs dictate.



Technology transfer

The analytical simulation study showed that high-efficiency electric air conditioning/dehumidification systems are often better than

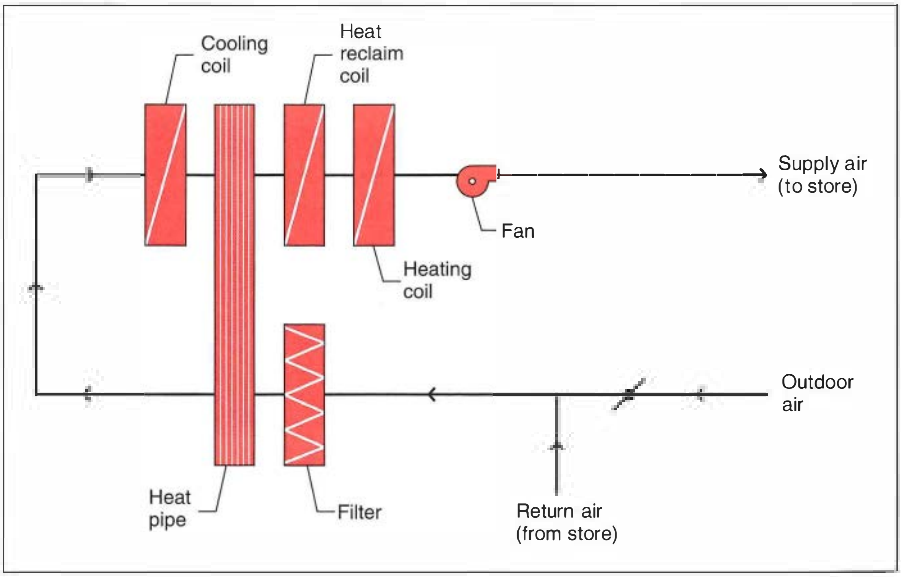


Figure 3 Heat-pipe-assisted system. A heat pipe heat exchanger allows for the transfer of heat directly from the warm air entering the cooling coil to the low-temperature air leaving the coil, thereby reducing both the cooling and reheating energy requirements. Such a heat exchanger can be used to enhance either improved single-path or dual-path electric air conditioning systems.

either conventional electric equipment or gas-fired desiccant equipment in terms of reducing supermarket capital and operating costs. These high-efficiency electric alternatives are available now.

Several EPRI-sponsored efforts have been completed or are under way to disseminate the results of this study to customers.

▫ A brochure, *Supermarket Air Conditioning and Dehumidification* (CU.3031.9.90), summarizes the technology benefits and system configurations and operating characteristics. A detailed report on the study is being prepared by the University of Wisconsin and should be available by the fourth quarter of 1991.

▫ At a seminar conducted in October 1990, 125 representatives of utilities, manufacturers, and supermarkets were briefed on efficient electric technologies for controlling humidity levels in stores.

▫ A forum held last March for utility representatives covered research needs and potential demonstration opportunities for verifying the results of this simulation study, identifying optimal system configurations, and developing applications guidelines for system designers and specifiers. Recommendations from this forum will help shape future EPRI dehumidification research.

▫ Work is under way for field tests of an improved single-path system with heat pipes and a dual-path system with heat pipes and cool storage.

Radiation Control

Cobalt Reduction in Nuclear Plants

by Howard Ocken, Nuclear Power Division

ABSTRACT *Because cobalt-60 is the largest contributor to general radiation fields at operating nuclear plants, a key aspect of EPRI's radiation control research has been to develop technologies that will reduce a plant's inventory of elemental cobalt. Recent efforts have made progress in eliminating the cobalt-base alloys used in components that require outstanding wear resistance, and in reducing cobalt impurity levels in construction alloys.*

Radiation surveys at nuclear plants have established that cobalt-60 is the largest contributor to general shutdown radiation fields and to discrete radiological particles found in PWRs. The sources of this radionuclide are (1) the cobalt-base alloys used to provide wear resistance to critical components, and (2) the cobalt present as an impurity in construction alloys, such as austenitic stainless steels and the Inconels.

EPRI-sponsored R&D has sought to eliminate cobalt-base alloys from reactor core components, to restrict the use of cobalt-base alloys to valves whose duty truly requires these high-performance alloys, to qualify for valves cobalt-free alloys whose properties and performance match those of the long-established cobalt-base alloys, and to identify realistic targets for cobalt impurity levels in materials used in nuclear plants. This report highlights recent progress and ongoing work in these areas.

Cobalt reduction guidelines

On the basis of their success in other industries, cobalt-base alloys were selected for nuclear applications long before their contribution to radiation fields was recognized. Subsequently, in 1989, EPRI organized a committee to review valve design and duty conditions and to develop guidelines identifying conditions under which the use of the cobalt-base alloys or their equivalent was required. The committee included utility personnel with expertise about valves as well as representatives of valve and nuclear steam supply system vendors.

The committee concluded that high-performance hard-facing alloys should be restricted to gate and globe valves that experience high contact stresses (>15 ksi). Available nickel-base alloys are suitable for gate and globe valves subjected to low contact stresses (<15 ksi) and for the pivot bushing of check valves. The committee saw no need to hard-face flow control valves and check valve seats, which are subject to general corrosion and cavitation-erosion damage; hardened martensitic steels perform adequately under these circumstances. The committee also wrestled with the issue of what tests were required to qualify new cobalt-free hard-facing alloys for demanding gate and globe valve applications.

Qualifying cobalt-free hard-facing alloys

Laboratory wear tests had identified a number of iron-base hard-facing alloys whose performance matched that of a cobalt-base standard, especially in resisting adhesive, or galling, wear. (This is the predominant wear mechanism when metal-to-metal contact occurs at high stress, as in valve trim.) Other laboratory tests found that the corrosion resistance and weldability of these candidate alloys were more than adequate for nuclear valve applications. EPRI deemed it necessary, however, to test the alloys in an actual component under conditions simulating those in a plant.

The approach taken in this testing (RP-1935-14) was to cycle gate valves that had been hard-faced with three iron-base alloys: the Thyssen Edelstahlwerke alloy Everit 50, the Stoody Deloro Stellite alloy EB 5183, and the EPRI-developed NOREM alloys. The tests imposed 2000 open-close-open cycles on valves under simulated PWR primary chemistry conditions. Two valves of each of the three alloys were evaluated, as well as one cobalt-base Stellite 6 valve, which served as a standard. Welding procedures required by the applicable ASME codes were developed, the hard facing was deposited, and nondestructive techniques were used to characterize the valve trim before startup of the loop. After each 500 cycles, the valves were characterized by means of such nondestructive techniques as dye penetrant tests, visual examinations, profilometry, and measurements of leak rates under hot and cold conditions. After 2000 cycles, the cobalt-base alloy showed the most damage, although the deepest wear scar measured was only 0.0006 mil.

The best overall measure of performance is probably the response of the valves in the leak rate tests. One valve hard-faced with EB 5183 and the valve hard-faced with NOREM 04 performed best in these tests, showing no leakage. Destructive examination of the disks and seats has been completed. The valve trim was replaced so that similar tests could be run under simulated BWR chemistry conditions; this testing began in August.

With the exception of the Everit 50 alloy, the valves discussed above were hard-faced with alloy powder deposited by the plasma transfer arc welding (PTAW) process, which can be used only in the shop. Because of the industry's need to repair valves at the site, EPRI's Nondestructive Evaluation Center implemented a project to develop in situ repair procedures using gas tungsten arc welding (GTAW). Work was limited to the NOREM alloys because Everit 50 routinely is deposited by GTAW and Stoody Deloro Stellite did not produce EB 5183 as wire.

The NDE Center procured NOREM weld wire and developed welding procedures. Although the initial successful work was performed with homogeneous weld wire, most of the work involved metal-core weld wire deposited by using standard GTAW equipment. The project met its goal—to deposit at least two layers of defect-free overlay on both carbon and stainless steel plate and piping specimens. It also demonstrated that the weld wire could be deposited without preheating the substrates. In addition, the project team found that intentionally introduced defects (cracks) could be repaired: the cracks were ground out and the grooves filled with new weld metal. Confirmatory laboratory tests of the wear resistance of NOREM weld overlays produced by using the newly developed welding procedures showed damage values as low as those found earlier in cast specimens and weld overlays produced by PTAW.

The focus now shifts to demonstrating the performance of NOREM alloys in valves used in operating nuclear power plants. EPRI is interested in supporting a program to use the alloys in globe or gate valves and to monitor performance over a number of operating cycles. Suitable candidates would be valves that are being replaced or refurbished.

Replacing cobalt-base alloys in BWR control blades

Pins and rollers guide a BWR control blade between the adjacent fuel channels. The earliest blades used cobalt-base alloys in the pins and rollers. Through corrosion and wear, these alloys become a key source of the cobalt that is responsible for general radiation fields. Computer calculations indicate that in some instances control blade pins and rollers account for 40% of general radiation fields.

EPRI-sponsored work led to the qualification of cobalt-free alloys for use in pins and rollers, and these alloys are now standard in the replacement blades offered by the vendor. Some utilities have chosen to replace their complete inventory of original control blades with the new cobalt-free ones. Others have adopted control-blade-shuffling schemes that reduce the rate at which the boron carbide poison is depleted, thereby minimizing control blade replacement costs. This approach results in the replacement of only a small fraction of the blades each year: after 10 years, only about 15% of the control blades will contain cobalt-free pins and rollers.

Replacing the high-cobalt pins and rollers would be a more attractive option if it could be performed cost-effectively on irradiated blades at the reactor site. EPRI has implemented a project with ABB Combustion Engineering to design, fabricate, and qualify hardware for removing the pins and rollers in the upper (in-core) end of a blade and replacing them with a stainless steel button riveted in place. Initial testing is expected to be completed by year's end and the equipment to be available for on-site use by next spring.

Controlling cobalt impurity levels in structural alloys

Utilities can also reduce plant cobalt inventories by specifying lower cobalt impurity levels in the replacement components they order. For example, it is possible to obtain steam generator tubing with a cobalt level of 0.015% rather than the 0.05% typical of original steam generators. Similarly, stainless steel for BWR control rod blades and piping can be obtained with a cobalt level of 0.02% rather than the 0.1–0.2% typical of early designs. Materials with lower cobalt levels can be obtained for only a small cost premium and will not affect component performance.

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Contractor: Franklin Research Center
EPRI Project Manager: G. Sliter

Examination of Kewaunee Steam Generator Tubes R4C81 and R11C9
NP-7370-M Final Report (RPS407-42); $200
NP-7370-S Final Report (RPS407-42); $5000
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: P. Paine

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Lighting Handbooks and Guidelines (RP2285-26)	$175,400 11 months	Eley Associates/ *K. Johnson*
Survey and Forecast of Market Demand and Supply of Energy-Efficient Lighting Products (RP2418-9)	$120,800 13 months	Lighting Research Institute/*K. Johnson*
Environmental Assessment of End-Use Technologies (RP2662-17)	$129,800 6 months	Energy and Environmental Research Corp./*T. Yau*
Improved Low-Cost Line Voltage Thermostat (RP2731-12)	$115,300 21 months	Honeywell/*J. Kesselring*
Performance Testing of Electric Thermal Storage Equipment (RP2731-14)	$100,000 8 months	Steffes ETS/*J. Kesselring*
Electrical Systems		
Establishment of Users Group Services for the OS/2 Version of EMTP (RP2149-12)	$74,800 16 months	Electrotek Concepts/ *R. Adapa*
National Lightning Detection Network: Operation, Maintenance, and Transfer for Commercialization (RP2431-7)	$6,600,000 119 months	Geomet Data Services/ *W. Shula*
Interactive Power Flow Program (RP2746-2)	$592,800 26 months	Ontario Hydro/*M. Lauby*
Cost-Benefit Analysis of Electric Power System Reliability, Phase 2 (RP2878-2)	$505,500 21 months	RCG/Hagler Bailly/ *M. Lauby*
Nationwide Residential Magnetic Field Measurements, Phase 2 (RP2942-13)	$942,000 12 months	Enertech Consultants/ *G. Rauch*
Host Utility for Thyristor-Controlled Series Compensation (RP3022-5)	$78,000 46 months	Bonneville Power Administration/*B. Damsky*
Adaptive Out-of-Step Protection Algorithm Analysis and Development (RP3022-9)	$62,200 28 months	Cornell University/ *L. Mankoff*
Environment		
Hydrocarbon Oxidation Pathways (RP2023-13)	$150,000 20 months	ESEERCO/*A. Hansen*
Response of Plants to Interacting Stresses (RP2799-7)	$303,700 26 months	Pennsylvania State University/*L. Goldstein*
Bioavailability of Manufactured Gas Plant Residues (RP2963-6)	$116.300 12 months	Rutgers University/ *L. Goldstein*
Exploratory and Applied Research		
Evaluation of Candidate Alloy High-Voltage Transmission Wires (RP2426-33)	$59,200 3 months	Battelle Memorial Institute/*R. Kennon*
Damage Assessment Using Positron Annihilation (RP2426-34)	$95,700 11 months	IIT Research Institute/ *R. Viswanathan*
Application of Yttrium-Aluminum-Garnet Lasers for Utility Diagnosis (RP2426-40)	$115,800 11 months	Foster Miller/*M. Lapides*
Generation and Storage		
Data Retrieval Software (RP2683-20)	$109,300 12 months	Fairfield Software/ *S. Drenker*
Plan for Quality and Productivity Improvement of Allen Plant Gas Turbines (RP2831-3)	$300,700 17 months	San Jose State University Foundation/*R. Frischmuth*
Oil- and Gas-Fired Boiler NO_x Emissions Database (RP2869-11)	$149,700 13 months	Electric Power Technologies/*A. Kokkinos*
Cycle Chemistry and Demineralizer Operation Expert System Advisor (RP2923-10)	$952,200 35 months	Sargent & Lundy Engineers/*B. Dooley*
Gas Turbine Hot Gas Temperature Measurement (RP2985-18)	$115,200 28 months	Conax Buffalo Corp./ *H. Schreiber*
Engineering and Construction Management Services for the 3-MW Selective Catalytic Reduction Pilot (RP3004-27)	$176,500 15 months	Brown & Caldwell/ *E. Cichanowicz*
Low NO_x/SO_2 Burner Retrofit for Utility Cyclone Boilers (RP3069-2)	$1,000,000 24 months	Transalta Technologies/ *A. Kokkinos*
Pulse-Jet Baghouse Performance Improvement With Flue Gas Conditioning (RP3083-9)	$250,300 24 months	University of North Dakota/*R. Chang*
System to Apply Real-Time Coal Quality Information to Utility Operations (RP3123-7)	$486,700 32 months	Oklahoma Gas and Electric Co./*D. O'Connor*
Fossil Plant Training Simulator Effectiveness Study and Procurement Guidelines (RP3152-1)	$496,800 33 months	General Physics Corp./ *M. Divakaruni*
Advanced Technology Transfer Network for Fossil Plants (RP3152-3)	$98,800 13 months	Sargent & Lundy Engineers/*M. Divakaruni*
Coal Ash Disposal Manual Update (RP3176-7)	$140,700 14 months	GAI Consultants/ *D. Golden*
GCC-Based Power and Fertilizer Coproduction Facility: Preliminary Design Study (RP3226-5)	$221,800 21 months	Tennessee Valley Authority/*N. Hertz*
Integrated Energy Systems		
Power Contract Planning System: POWERMIX (RP3145-10)	$250,300 10 months	Decision Focus/*H. Mueller*
Emissions Trading Market Simulation Laboratory (RP3306-1)	$167,800 22 months	Decision Focus/*G. Hester*
Nuclear Power		
Development of an Enhanced Fuel Performance Predictive Capability: ESCORE, Version 2 (RP2061-26)	$524,100 31 months	S. Levy/*O. Ozer*
Maintenance Manual: ABB K-Type Low-Voltage Breakers (RP2814-34)	$109,800 6 months	ABB Power Distribution/ *J. Christie*
Electric Motor Predictive and Preventive Maintenance Guide (RP2814-35)	$91,600 10 months	Bechtel Group/*B. Varma*
Pilot Test of Electrochemical Separation of Hydrogen From BWR Oft-gas (RPC101-18)	$55,600 8 months	Grove Engineering/ *M. Behravesh*
Stress Corrosion Cracking in Low-Alloy Steels (RPC102-4)	$1,336,500 45 months	General Electric Co./ *R. Pathania*
Guideline for Use of Microcomputers in Safety-Related Applications (RPQ101-28)	$55,800 10 months	Vanguard Technologies/ *W. Bilanin*
Primary-Water Stress Corrosion Cracking Characterization of Hydraulic Tube-Tubesheet Expansions (RPS406-12)	$274,100 11 months	Westinghouse Electric Corp./*A. McIlree*
Investigation of Lead as a Cause of Intergranular Attack at Support Plate Intersection (RPS408-7)	$213,200 16 months	Babcock & Wilcox Co./ *A. McIlree*
Evaluation of Amine-Type Inhibitors as Crevice Buffers (RPS409-14)	$95,000 9 months	SRI International/*P. Millet*
Advanced Thermal-Hydraulic Analysis of Steam Generators (RPS411-7)	$94,900 11 months	CFD Research Corp./ *G. Srikantiah*
Relationship of Radiation-Induced Segregation Phenomena to Stress Corrosion Cracking (RPX102-3)	$73,000 7 months	Nuclear Electric plc/ *L. Nelson*
Gosgen Project: Post-Irradiation Characterization (RPX102-11)	$650,100 46 months	Paul Scherrer Institute/ *S. Yagnik*

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

NOVEMBER

4–6
International Conference: Managing Hazardous Air Pollutants
Washington, D.C.
Contact: Lori Adams, (415) 855-8763

5–6
Workshop: Cooling Tower Performance Prediction and Improvement
Eddystone, Pennsylvania
Contact: John Bartz, (415) 855-2851

5–7
Boiler Tube Failures in Fossil Plants
San Diego, California
Contact: Linda Nelson, (415) 855-2127

6–7
1991 Fuel Oil Utilization Workshop
San Antonio, Texas
Contact: William Rovesti, (415) 855-2519

7–8
Planning Your First Transmission Cable Project (Short Course)
St. Petersburg, Florida
Contact: John Shimshock, (412) 722-5781

12–15
Maintenance Proficiency Evaluation Training Course
Charlotte, North Carolina
Contact: Loran Maier, (704) 547-6152

13–14
Seminar/Workshop: Evaluation of Distribution Automation Systems
Dallas, Texas
Contact: Tom Kendrew, (415) 855-2317

13–15
Power Quality Hands-on Training Course
Knoxville, Tennessee
Contact: Donna Eason, (615) 675-9505

14–15
Workshop: CLASSIFY PLUS—Meeting Commercial Customer Needs
Charlotte, North Carolina
Contact: Thom Henneberger, (415) 855-2885

19–20
NMAC Workshop: Circuit Breakers
East Dundee, Illinois
Contact: Jim Christie, (704) 547-6053

19–21
Rotating Machinery Balancing: ROBAL
Eddystone, Pennsylvania
Contact: Tom McCloskey, (415) 855-2655

DECEMBER

2–6
Fireside Performance of Coal-Fired Boilers (Short Course)
Charlotte, North Carolina
Contact: Bob Leyse, (415) 855-2995

3–4
NMAC Workshop: Circuit Breakers
Middletown, Connecticut
Contact: Jim Christie, (704) 547-6053

3–5
Strategic Cost and Quality Management
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

3–6
Symposium: SO_2 Control
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

4–6
NMAC Workshop: Solenoid-Operated Valves
Clearwater Beach, Florida
Contact: Vic Varma, (415) 855-2771

10–12
Power Quality Hands-on Training Course
Knoxville, Tennessee
Contact: Donna Eason, (615) 675-9505

10–12
Utility Motor and Generator Predictive Maintenance Workshop
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

11–13
Seminar: Demand-Side Management on Target—Concepts, Players, and Practices
Phoenix, Arizona
Contact: Larry Lewis, (415) 855-8902

12–13
NMAC Workshop: Circuit Breakers
Charlotte, North Carolina
Contact: Jim Christie, (704) 547-6053

JANUARY 1992

16–17
Workshop: CLASSIFY PLUS—Meeting Commercial Customer Needs
Dallas, Texas
Contact: Thom Henneberger, (415) 855-2885

29–31
Conference: Steam and Combustion Turbine Blading
Orlando, Florida
Contact: Lori Adams, (415) 855-8763

FEBRUARY

5–7
Advanced Digital Computers, Controls, and Automation Technologies
San Diego, California
Contact: Pam Turner, (415) 855-2010

6–8
Industrial Safety Innovations in Nuclear Power Plant O&M
Charlotte, North Carolina
Contact: John O'Brien, (415) 855-2214

MARCH

3–5
Seminar: Substation Voltage Uprating
Denver, Colorado
Contact: Joe Porter, (202) 872-9222

16–17
Investment and Research Planning Forum
Atlanta, Georgia
Contact: Susan Bisetti, (415) 855-7919

APRIL

8–9
Asbestos Control and Replacement for Utilities
Pittsburgh, Pennsylvania
Contact: Linda Nelson, (415) 855-2127

MAY

31–June 4
International Conference: Mercury as a Global Pollutant
Monterey, California
Contact: Pam Turner, (415) 855-2010

JUNE

1–3
2d Annual ISA-EPRI Controls and Automation Conference
Kansas City, Missouri
Contact: Lori Adams, (415) 855-8763

3–5
International Conference: Interaction of Iron-Based Materials With Water and Steam
Heidelberg, Germany
Contact: Barry Dooley, (415) 855-2458

Authors and Articles


Gillis


Rastler


Armor


Tsou


Mattice


Edwards


Joyner

Fuel Cells for Urban Power (page 4) was written by science writer John Douglas with information provided by two members of EPRI's Advanced Fossil Power Systems Department.

Ed Gillis, senior program manager for fuel cells research, came to EPRI in 1976. He was formerly with the Army's Mobility Equipment R&D Command for 12 years, ultimately as chief of the electrochemical division. From 1958 to 1964, Gillis was with Allis-Chalmers. He is a mechanical engineering graduate of Marquette University.

Daniel Rastler has been with EPRI since 1981, serving as project manager for research on a variety of fuel cell systems. He previously spent five years with General Electric's Nuclear Energy Division, four years in the U.S. Air Force, and a year with Toscopetro Corporation. Rastler received a BS in chemical engineering from the University of California at Davis and an MS in mechanical engineering from UC Berkeley. ■

Invasion of the Striped Mollusks (page 12) was written by Leslie Lamarre, *Journal* feature writer, with assistance from the Generation and Storage, Environment, and Nuclear Power divisions.

Tony Armor became director of the Fossil Power Plants Department in the Generation and Storage Division in January of this year. Previously he headed the Fossil Plant Performance Program. Armor came to EPRI in 1979 as a project manager. Before that he was a program manager for superconducting generator design at General Electric, where he worked for 11 years. Armor has a BS in mathematics and an MS in mining engineering from the University of Nottingham in England.

John Tsou, a project manager in the Fossil Plant Performance Program, joined the Institute in 1985. Before that he managed an engineeering department at McQuay, Inc., for nine years and held engineering positions with other U.S. firms, including Riley-Beaird, Colt Industries, and Aqua-Chem. He also was a marine engineer with Marine Industries in Hong Kong. He received a BS in marine engineering from the Taiwan Maritime College.

Jack Mattice is a senior project manager in the Ecological Studies Program. He joined EPRI in 1981 after nine years with Oak Ridge National Laboratory, where he was a research staff member in the environmental sciences division. He has a BS in biology from the State University of New York at Stony Brook and a PhD in invertebrate zoology from Syracuse University.

Bob Edwards, a project manager in the Engineering and Operations Department of the Nuclear Power Division, joined EPRI in 1990. His previous experience includes power plant engineering design and project management for Bechtel, where he worked for 15 years. He also served as a presidential exchange executive with the U.S. Department of Energy for one year. He has a BS from Tuskegee Institute and a JD from Golden Gate University. ■

John Sawhill Gets Things Going (page 20) profiles the former head of both the Federal Energy Administration and the Synthetic Fuels Corporation. Now president of the Nature Conservancy and a member of EPRI's Advisory Council, Sawhill was interviewed for this article by writer Ralph Whitaker. ■

Heat Pumps for Northern Climates (page 28) was written by Michael Scofield, science writer, with background information provided by **Powell Joyner** of the Customer Systems Division.

Joyner is the technical manager for advanced projects in the Residential Program. He came to EPRI in 1985 after 17 years with Trane Company, where he was vice president for research on HVAC systems and industrial fume incineration. From 1963 to 1968, he worked for Allis-Chalmers, and still earlier he held scientific and management posts at Honeywell and at Callery Chemical Company. Joyner graduated in physics from Centenary College; he holds a PhD in physical chemistry from the University of Iowa. ■

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