Electric Vehicles for the '90s

Also in this issue • *EV Batteries* • *Clean Air Act Compliance* • *SO_2 and Health*

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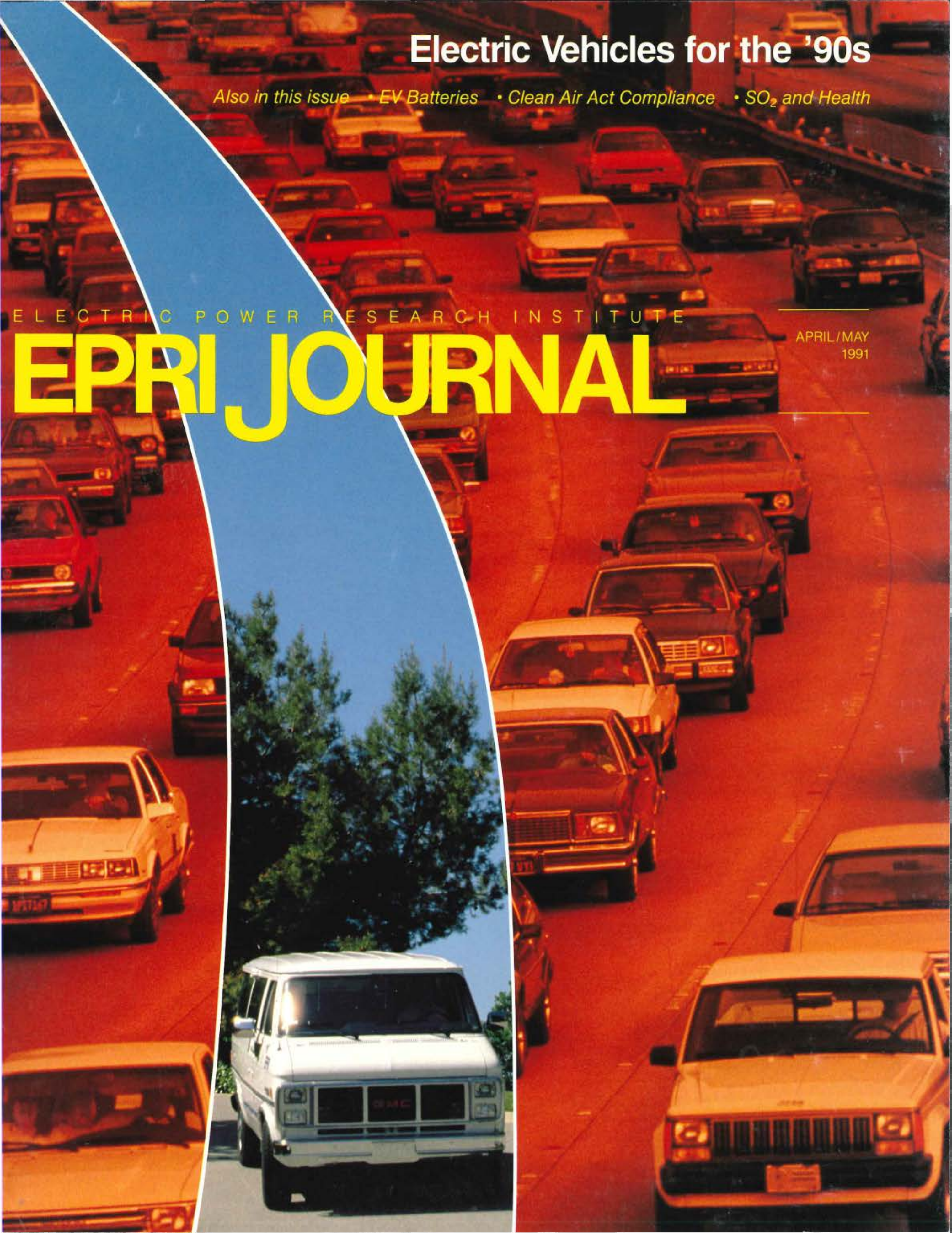

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Cover: Urban air quality, which has suffered from long-term growth in automobile exhaust emissions, is the principal driver behind the new interest in electric vehicle development.

Electric Vehicles on the Road to a Comeback

Transportation in all its forms plays a vital role in America's economic and social well-being, particularly in the free flow of commerce and in the freedom of individuals to live, work, and relax where they choose. No other mode of transportation reflects this desire for mobility more strongly than the millions of cars and trucks running on the nation's far-reaching network of roads and highways.

Yet the tremendous success of internal combustion vehicles as an economic and social force over the last century has ironically led to the emergence of an array of adverse issues that are now driving fundamental change in transportation vehicle technology. The issues are the obvious ones—the growing public desire for a cleaner environment, the national security implications of our nearly 50% dependence on imported oil, and the multibillion-dollar deficit in our balance of trade with other countries.

At EPRI, where we have advocated and nurtured electric vehicle technology for over a decade, we are delighted that all three U.S. auto companies now have active EV development programs under way. As part of a major effort by automobile manufacturers to shift to the cleanest, nonpetroleum-based vehicle systems possible while preserving maximum mobility, electric vehicles are again being seriously considered among the alternatives for development. Regulatory attention in California and elsewhere has provided new impetus to the marketplace. We look forward to continuing to work with auto and battery manufacturers as efforts to develop advanced vehicles and systems gain momentum.

Continued participation of the electric utility industry in a widening EV development community is essential if electric vehicles are to be successful in the consumer market. Not only are utilities currently being asked to support an expanded, collaborative effort with the auto companies and the government to develop advanced batteries for EVs, but they are also expected to develop the customer support infrastructure necessary to make EVs convenient to use.

This month's cover story details the many recent developments in electric vehicles, as well as EPRI's changing role among a growing circle of participants in what promises to be an exciting decade of change in transportation vehicle technology.

Lawrence O'Connell

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Customer Systems Division

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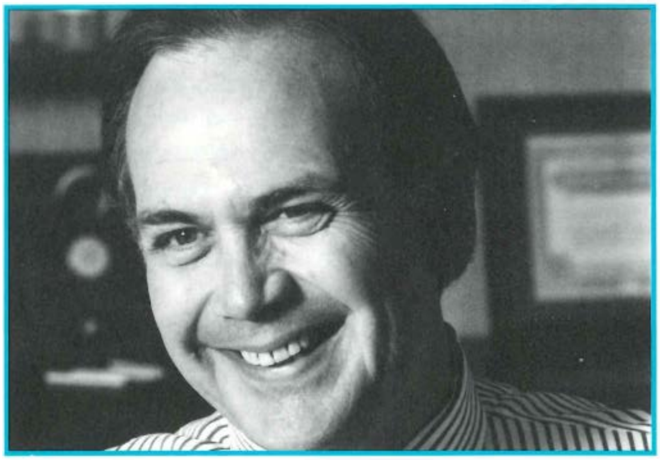

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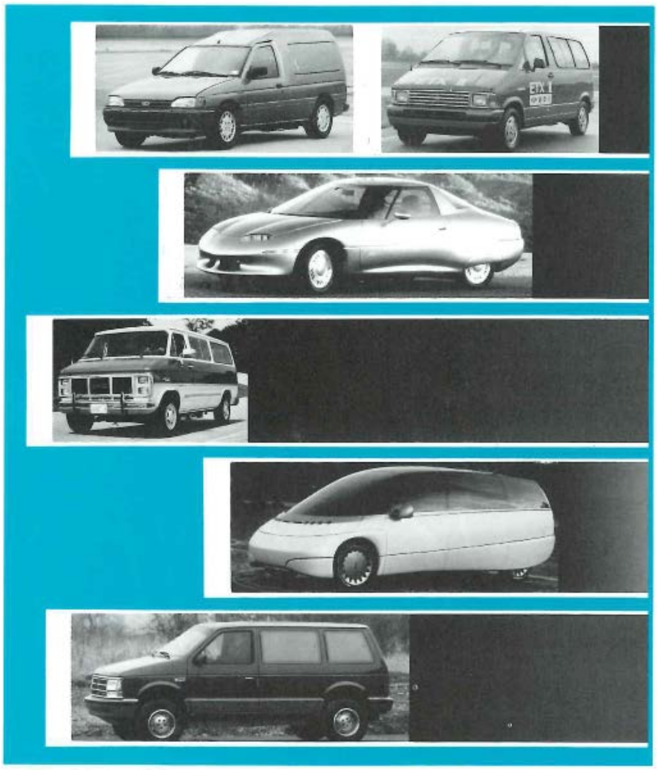

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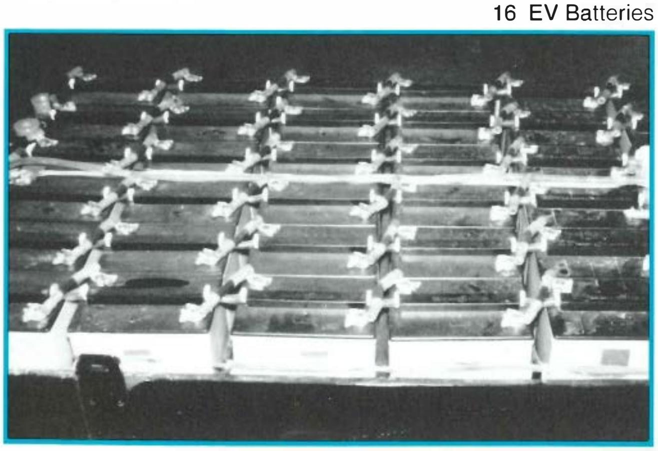




They're New!

They're Clean!

They're Electric!

At the turn of this century, as the Automobile Age was beginning to take root on the country's economic and technological landscape, electric cars were the chief competitors of steam-powered vehicles, then the most popular form of automotive transport. Gasoline-powered internal combustion models held less than a quarter of the fledgling market in horseless carriages. Quiet, clean-running, and easy to operate, electric cars were the choice of most women drivers of the day, including Henry Ford's wife, Clara.

Yet within little more than a decade, technology innovation and the public's thirst for speed and power on the road sealed America's transportation future behind the wheels of gasoline-powered automobiles for nearly the next hundred years. Ironically, the introduction of the electric starter eliminated the gasoline car's main early drawback: its need of strong and sometimes persistent hand cranking. Ford's genius for mass production soon made such cars as the Model T widely affordable. And as the American love affair with the open road bloomed, the range, convenience, and raw power embodied in such a high-energy fuel as gasoline left its transportation rivals in the dust.

Now, in the century's final decade, with the environmental and geopolitical ramifications of oil-dependent transportation all too apparent, electric vehicles may be nearing a historic comeback. After false starts at reviving electric vehicles in the 1970s, American automakers are in the midst of making a major commitment to bring practical and economical EVs into commercial production by the latter half of the 1990s.

Individual and collaborative R&D efforts by U.S. vehicle and battery manufacturers, the federal government, EPRI, and electric utilities are aiming to provide a technology base that will ensure a future for EVs as a viable transportation option. Chief among the collaborations is a major new consortium formed earlier

THE STORY IN BRIEF

The 1990s appear to be the decade in which the long-sought dream of practical, economical electric vehicles will begin to be realized. Regulatory efforts to improve urban air quality in California have already renewed the auto industry's interest in EVs, and recently revived concern over foreign oil dependence has fueled the fire in the national political sphere. As the first commercial vehicles hit the road in niche markets and as designs for more-advanced vehicles take shape on design boards, the major U.S. automakers have agreed to unprecedented cooperation in bringing advanced EV batteries to commercial development through the recently formed U.S. Advanced Battery Consortium. They are now enlisting support from electric utilities, through EPRI, both for the consortium effort to develop advanced batteries and for the development of appropriate infrastructure standards and technology that will make EVs easy for consumers to use.

EVs a Clear Winner in Reducing Vehicle Emissions

Electric vehicles produce zero pollution emissions in operation. Even accounting for the power plant emissions associated with generating the electricity for battery recharging, EVs represent a dramatically cleaner form of transportation than conventional gasoline vehicles. The emissions represented by the energy consumption of an efficient electric minivan, such as the TEVan under development by Chrysler, are much lower than the direct emissions of four key pollutants from a current gasoline-powered minivan. TEVan-related power plant emissions are stated to reflect both the current U.S. generation mix and that expected with new generating capacity installed after 1995.

	Emissions From Gasoline-Powered Minivan (grams/mile)	Emissions From Electric TEVan (grams/mile)	
		Under Current Generation Mix	Under Post-1995 Generation Mix
Carbon monoxide	10	0.05	0.05
Nitrogen oxides	1.8	1.2	0.3
Volatile organic compounds	1	0.01	0.01
Carbon dioxide	690	315	320

this year by Chrysler, Ford, and General Motors—and soon to be joined, through cooperative agreements, by the Department of Energy and by EPRI on behalf of the electric utility industry. The goal is to develop advanced EV battery technologies by the mid to late 1990s. Meanwhile, similar and potentially competing efforts are said to be under way in Japan and Europe.

An unusual array of positive forces seems to be in convergence for EVs. Tough new air quality rules planned in California virtually mandate that 2% of all new vehicles sold in the state—around 40,000 at the present annual rate—be electric-powered or otherwise designed to emit zero pollution, by 1998. The regulatory quota for such vehicles would rise to 10%, or about 200,000 vehicles per year, in 2003. Government agencies and utilities in the Los Angeles area last year launched an effort—called the L.A. Initiative—to encourage the commercial introduction of 10,000 electric vehicles there by 1995. Meanwhile, limited commercial production began in Ontario last fall of the electric G-Van for fleet service. The result of an EPRI-led development effort, the G-Van is initially being marketed to utilities and will eventually be marketed to other van fleet operators. And one of the biggest sparks in years for public interest in EVs came just after New Year's Day 1990 when General Motors showed off a sleek and zippy two-seater electric concept car called the Impact. GM said just a few months ago that it will convert one of its Michigan plants to build a passenger EV much like the Impact, beginning within a few years.

The Impact was designed from the ground up as the most efficient and advanced electric passenger car yet built as a concept vehicle, and its design, acceleration, and speed set off a new wave of interest in EVs. It proved that it is possible to match gasoline-powered cars in at least some measures of performance, even with today's limited and heavy lead-acid batteries.

The driving range of EVs likely will never equal that of conventional vehicles, even with substantially improved batteries such as those under development here and abroad. Yet for many vehicle applications, range is not a primary consideration. Just how much of a consumer market will develop for EVs—with how much less range than conventional vehicles—is the big question.

Electric vehicle development figured in President Bush's new National Energy Strategy, revealed last February against the backdrop of war in the Persian Gulf. In addition to measures to encourage the conversion of some fleet vehicles to alternative fuels, including electricity, the plan proposed substantial increases in federal funding over the next several years for battery R&D, representing the government's participation in and strong support for the new U.S. Advanced Battery Consortium (USABC). The Big Three automakers said the consortium hopes to raise $35 million this year, and to increase that figure soon to $100 million a year, to develop interim and longer-term batteries that could eventually be licensed by the car companies for use in competitive EV models.

"The outlook for the future of EVs has never been brighter," says Larry O'Connell, EPRI's senior program manager for electric transportation. "The combination of pressures to improve urban air quality in dozens of cities, pressures to begin to do something about our heavy reliance on oil for transportation, and anticipated research advances, including much-improved batteries, could mean the 1990s will be for electric vehicles what the 1980s were for the personal computer—a decade of emergence from oblivion to ubiquity."

Collaboration for competitive survival

Most observers agree that California's planned air quality regulations are the major driving force behind Detroit's new interest in EVs. With 10% of the country's new vehicle sales occurring in the Golden State, and with California's traditional lead among states in tightening air quality and vehicle emissions rules, automotive developments there tend eventually to reach the nation at large.

But there are also signs that the Big Three are coming to recognize a strategic role for EVs as a matter of competitive survival. After a decade of seeing their combined share of the U.S. automobile market slide from nearly three-quarters to two-thirds against stiffening competition from Asian and European manufacturers, U.S. carmakers are anxious to regain a competitive edge. They also know that many of their overseas-based rivals are working on EVs and advanced batteries of their own.

To fully design, engineer, and develop manufacturing and tooling for a new line of EVs—not to mention the sorts of batteries they will need to compete with conventional vehicles—could require the investment of hundreds of millions of dollars by each of the Big Three over the next decade, insiders say. Given the recent recessionary economic conditions and coming at a time when some of the worst months for new vehicle sales in years are severely pinching profits and causing plant closures and worker layoffs, Detroit's cautious reexamination of a new, long-term technical and vehicle development path is marked by risk and uncertainty.

"The things we are most certain about now are the uncertainties," says Kenneth Baker, manager of electric vehicle development for GM and the first chairman of the U.S. Advanced Battery Consortium. "The way EVs can appeal to the broadest consumer market is if there are advanced battery technologies able to satisfy more customers' needs. We have to make the battery a nonissue for the consumer and put the competitive focus among the manufacturers on the vehicles themselves. GM has decided to introduce EVs with lead-acid batteries but to also aggressively pursue advanced battery technologies for the long term."

The USABC's aim is to select and develop the most promising second- and third-generation battery technologies over the next 10 to 12 years and license them for manufacture in future joint ventures between individual makers of cars and batteries. Depending on utility industry support, now being solicited, the consortium hopes to have technical working groups in place this summer in what organizers hope will grow to a $100-million-a-year development program by 1993.

In the first of a series of meetings with utility officials since the USABC's formation, Baker last February outlined why the consortium approach has the best chance of success to develop battery technologies for future generations of EVs. First, there is no clear choice among the several technologies that might be developed to yield practical, long-range, long-life EV batteries. And the level of investment necessary to develop any of them is potentially quite high. A collaboration among partners can build on their collective strengths and focus on a few programs in order to increase the probability of success. The approach promises to accelerate the development of both batteries and vehicles (although the consortium will neither develop vehicles nor manufacture batteries) and is expected to provide a higher rate of return on investment in new technology than would otherwise be possible.

Baker said utility industry participation is essential to the success of the battery consortium, not only because utilities' financial support is needed but also because of the energy-related and technical infrastructure details that must be cooperatively worked out before EVs begin to reach the market. Consortium officials have been meeting with utility executives in recent months to solicit commitments of support.

One utility that is already solidly behind the USABC is Southern California Edison, one of the leading utility industry advocates of EVs. Along with EPRI and Chrysler, SCE is cofunding engineering development of the electric TEVan, based on Chrysler's popular Dodge and Plymouth minivans. The utility has also bought 15 of the preproduction, EPRI-developed G-Vans and uses them in its own service fleet and for demonstrations for fleet operators and government agencies. SCE and the Los Angeles Department of Water & Power are cosponsors of the L.A. Initiative commercialization effort for EVs.

"If we're ever going to make EVs work, the time is now, and we have to get moving to develop the necessary battery technology. This consortium is definitely the way to go," says Robert Dietch, SCE's vice president for engineering, planning, and research. "I certainly believe that we are going to begin to see EVs in California this decade and that they're going to spread across the country. I hope the electric utilities do not miss the opportunity to be a key player, and not just a passive spectator, in this business."

As this article was being prepared, EPRI was negotiating a cooperative agreement for participation with the USABC. SCE expects to support the battery consortium through a separate agreement with EPRI. Although the Institute's nonprofit status constrains it from full partnership in the consortium, it is "negotiating an agreement that allows EPRI and the utility industry to fully participate without being a direct partner," according to Jack Guy, manager of commercialization in EPRI's Customer Systems Division. Guy, who helped organize an initial meeting between auto and utility executives last year before Detroit's formation of the consortium, says the USABC seeks funding support from the utility industry of about $8 million to $9 million per year, some $3 million of which is anticipated to come from EPRI.

EPRI research managers acknowledge that, as suggested by the commitment of

The G-Van: Blazing the Trail for Fleet Service

Commercial production of the 1-ton G-Van was begun last year by Vehma International, culminating a four-year, EPRI-led development program involving Vehma (a unit of Magna International), Chloride EV Systems of Britain, and General Motors Corporation, with additional support from Southern California Edison Company. The full-size electric cargo or passenger van is being marketed to electric utilities for fleet use and will eventually be sold to commercial fleet operators through GM dealerships. While the G-Van now runs on lead-acid batteries, more-advanced batteries may be incorporated as they become available.

G-Van Specifications	Range on full charge: up to 60 miles
Top speed: 52 mph	Recharging: 8 hours on 240-volt outlet
Acceleration: 0 to 30 mph in 13 seconds	Payload: 1550 pounds cargo or 5 occupants
Batteries: 36 6-volt lead-acid	Energy consumption: 1 kWh per mile

the auto companies to EV development and the USABC's battery effort, something of an evolution is under way in the national EV picture and, in turn, in the Institute's R&D program. GM's Baker refers to it as a changing of the guard.

Over the years, utilities, the auto companies, and government agencies have separately invested in battery R&D. "Now, collectively, we have a chance to lead the way in environmental and energy management for transportation," Baker told utility officials at the February meeting. "Because the EV is so important to all of us, we need to work toward a successful launch plan. The auto companies will develop the vehicles, but we will still be counting on utilities for the energy supply and infrastructure." In anticipation of these developments, EPRI had already increased its R&D focus on infrastructure requirements—both technology and customer service—and it now plans to support EV battery development through the USABC.

A puzzle within a promise

With some 185 million gasoline vehicles on the road in this country and between 6 and 7 million new ones added annually, the environmental appeal of EVs is compelling. More than half of all Americans live in areas where smog-related ozone levels often exceed the federal standard, and a third of the population lives where carbon monoxide sometimes reaches unhealthful levels. In the 100-plus urban areas where air quality is frequently poor, changing just a small fraction of the gasoline vehicle market to electric power could make a dramatic difference in air quality because EVs are so overwhelmingly less polluting—even taking into account the power plant emissions associated with generating the electricity to run them.

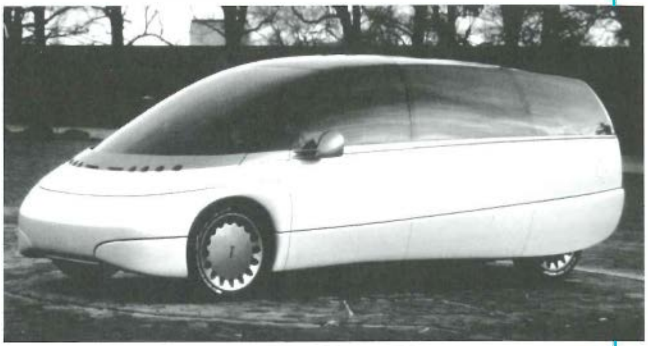
Estimates by the California Air Resources Board indicate that EVs in the Los Angeles basin result in 98% less hydrocarbon emissions (a key contributor to ozone and smog) per mile than gasoline vehicles, 89% less nitrogen oxides, 99% less carbon monoxide, and less than half as much carbon dioxide. An extensive analysis of the air quality implications of EVs was recently made for EPRI and the South Coast Air Quality Management District by the Washington, D.C., think tank Resources for the Future. RFF estimates that the introduction of 1.5 million EVs in the Los Angeles area would reduce peak ozone concentrations by about 4%, to a level nearly 20% below that projected for the region by 2010. Comparable air quality improvements for a similar level of EV use were estimated for other urban regions. The study found that the urban use of EVs could even lead to net reductions of ozone in rural areas downwind.

For some pollutants, however, the environmental case for EVs is not absolute. Depending on the mix of generating resources used to supply electricity for EVs, their wide adoption conceivably could cause small increases in fossil fuel plant emissions of sulfur oxides, implicated in acid rain. But emissions that are, in effect, transferred from a vehicle on the road to a power plant are inherently easier and more economical to control, say EV proponents.

An electric vehicle future would not

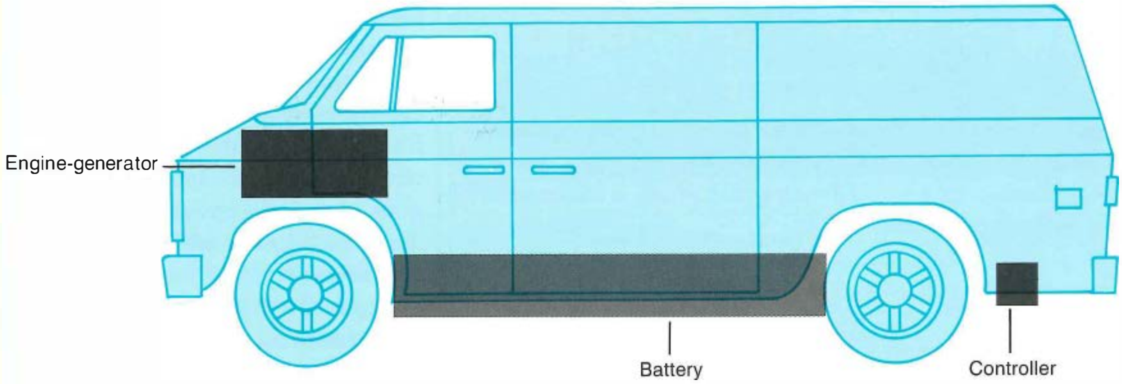
Hybrid Electric Vehicles for Extended Driving Range

Many EV developers are interested in hybrid vehicles that employ a small engine-generator to supplement battery power to the electric motor drive as a way to boost vehicle driving range before advanced batteries become available. On shorter trips the EV battery pack would provide all of the power for propulsion, but on longer trips the generator (similar to those used in recreational vehicles) would work in combination with the batteries to extend their discharge time. Such an arrangement can extend the range possible with lead-acid batteries alone by a factor of 2 or more. Although gasoline-powered, the generators can be optimized for very low emissions. General Motors has shown a concept hybrid electric van called the HX-3 but has announced no plans for production. EPRI is sponsoring engineering design and prototype development of an extended-range hybrid version of the G-Van, which could get as much as 120 miles on a single charge of its lead-acid battery pack with supplemental generator power. The schematic shows how the engine-generator would replace the motor controller in the front of the vehicle, with the controller moving to the rear underside of the van.



GM's HX-3 hybrid concept van

Extended-range hybrid G-Van



require new power plants, experts say. The energy demand of very large numbers of EVs, if they were recharged off-peak, could easily be supplied by existing generating capacity that is normally idle at those times.

According to Richard Schweinberg, SCE's manager of electric transportation, the energy demand of as many as a million EVs in the Los Angeles basin could be accommodated with available off-peak generating capacity and no need for new power plants. Taking the analysis even further, EPRI calculates that existing off-peak generating capacity in the country is sufficient to handle the overnight recharging of at least 50 million efficient EVs.

True, EVs represent a potential new market for electricity on the order of hundreds of billions of kilowatthours. But if most of that electricity was generated for recharging EVs at night, utility system load and plant utilization factors would improve. For example, SCE estimates that 1 million EVs traveling 15,000 miles a year apiece could represent annual electricity use of 7.5 billion kWh. If that electricity was generated off-peak, such a level of consumption could improve the utility's system load factor by 4%.

"Electric vehicles are source-energy efficient," says Geoffrey Bales, manager of research at SCE. "They are a perfect example of a way to conserve primary energy by substituting a more efficient form of energy at the point of use. Some people label EVs as just something to build load for utilities, but they are much more than that. They offer both cleaner air and energy efficiency."

In addition to the air quality and load factor benefits, EVs could help significantly reduce dependence on petroleum-based fuel for transportation. According to government figures, nearly two-thirds (63%) of the 17 million barrels of oil consumed each day in the United States goes for transportation, and of that, more than half (59%, or more than 6 million bpd) goes to fuel autos, light trucks, and vans. Less than 5% of the nation's electricity is generated by burning oil. Each EV represents a potential reduction in demand for oil of 10–20 barrels per year.

Yet for all their obvious benefits, EVs have always posed a puzzle within their great promise. "It's the classic 'chicken or the egg' problem," says Gary Purcell, a project manager in EPRI's Electric Transportation Program. "How do vehicle manufacturers stimulate consumer demand to justify the investment to fully develop EVs without vehicles that are competitive early on in price and range and without the infrastructure of service, support, and energy recharging that consumers will expect? On the other hand, battery companies and utilities have been reluctant to commit significant resources to establishing new manufacturing capability or energy and service infrastructure until they see evidence of a strong market in the form of vehicle sales." So which comes first, asks Purcell, the technology and vehicles or the market demand?

Proponents of EVs hope the new battery consortium will be able to break the historical stalemate. Traditionally, American automobile manufacturers have been enjoined by federal antitrust laws from cooperating on technical and product developments. But the USABC is taking encouragement from the 1984 National Cooperative Research Act, which has spawned industry collaborations in semiconductors, home automation, and other areas by lessening antitrust restrictions. The battery consortium won almost immediate endorsement from the Bush administration, which has proposed that DOE provide half of the effort's R&D funding.

Batteries have always been the key limiting technology for EVs (see the accompanying battery article in this issue). With the launch of the USABC, Detroit is

Challenges in EV Customer Support Infrastructure

With a major collaborative industrial R&D effort under way to develop advanced batteries for electric vehicles and a commitment emerging from automakers to develop EVs in the 1990s, electric utilities are expected to develop much of the customer support infrastructure. This will include hardware as well as service and support features necessary to make EVs convenient to use. Representatives of utilities, auto companies, battery manufacturers, and other interested parties have launched technical working groups to explore infrastructure issues and coordinate technical details. EPRI is refocusing some of its EV-related research on developing the technology for various aspects of EV infrastructure.

Recharging Post-1995 EVs will have on-board electronic chargers for plug-in recharging on a 220-volt outlet, but there may also be a need for public-access charging stations in parking lots and garages. There are possibilities for curbside induction charging. Or smart meters could be programmed to recharge EVs at off-peak periods. A host of technical and business details are yet to be developed.

Standardization The interface between all EVs and the electricity supply will have to be standardized for customer safety and convenience. This would include programmed microprocessor controls on vehicle chargers, as well as standardized electrical cables and outlet connections.

Billing systems Special energy accounting and billing systems will have to be developed for public-access and opportunity-charging stations—systems that incorporate time-of-use electricity pricing incentives to encourage off-peak recharging. Advanced billing hardware, such as hardware for point-of-sale electronic funds transfer, will be investigated.

Safety Fundamental electrical safety issues must be resolved through existing industry standards organizations. Research is needed to address other possible safety-related concerns, including electromagnetic field exposure.

Sales and service Fleet EVs initially will be serviced through utility-established EV service centers. Vehicle manufacturers are expected to eventually provide service and support through dealers. Utilities could become involved in battery sales and leasing.

strongly signaling its desire to ensure that, if automakers invest heavily in vehicle design and development in the decade ahead, advanced batteries will also be developed and ready in time to build into the mass-market EVs that could eventually be offered to consumers.

Emerging vehicles and market niches

No single electric vehicle will satisfy the needs of all segments of the diverse U.S. vehicle market. Developers envision an assortment of EVs with different levels of performance and range to compete with conventional vehicles. Perhaps the biggest part of the consumer market is in the family or commuter passenger car. Detroit automakers believe that in order for EVs to compete with conventional cars on a broad front, advanced battery systems will have to provide EVs a range of 300 miles or more and should last for 100,000 miles of use with recharging.

But for more limited and narrowly defined market segments, far less performance is necessary. Urban service and delivery fleets have always seemed an attractive entry niche market for EVs because 80% of that market involves daily travel of 60 miles or less in vehicles that are centrally parked and serviced overnight.

While automakers are talking about building EVs for the passenger vehicle market in the future, there is one fully engineered EV that is already being commercially produced: EPRI's G-Van, manufactured by Vehma International, a vehicle development subsidiary of the Canadian auto parts maker Magna International. Vehma this year is producing approximately 100 of the 1-ton, full-size vans, designed primarily for fleet service, by combining GM-supplied Vandura bodies with electric propulsion and battery systems supplied by Chloride EV Systems of Great Britain. Equipped with a 2600-pound underpack of deep-discharge lead-acid batteries, the G-Van has a driving range of up to 60 miles between 8-hour rechargings and a top speed of 52 mph. It accelerates from 0 to 30 mph in 13 seconds.

Utilities in over two dozen cities are beginning to put the G-Vans to use as orders are filled and vehicles are delivered. As well as in California, utilities in Florida, New Jersey, New York, Texas, and other states are buying G-Vans to get early hands-on operating experience and familiarity with EVs. Commercial production of the G-Van culminates a four-year development effort that included full certification to federal vehicle safety standards and extensive field testing of over 25 prototypes by utilities and other fleet operators. In addition to major support from EPRI, Vehma, and Chloride EV Systems, support was provided by GM, SCE, and DOE.

"The only way utilities can start to help develop the infrastructure for EVs is to have some vehicles in hand now for use in their own fleets and by some of their commercial customers. And the G-Van gives them the first opportunity for that," says EPRI's Purcell. "The real bonus of the G-Van is that it will help utilities learn the practical aspects of what kind of infrastructure support is needed." In its development, the G-Van has served as a test-bed for several inno-

The TEVan: An Electric Minivan for the Consumer Market

Under a two-year agreement with EPRI, Chrysler Corporation is developing a number of engineering prototypes of the TEVan—an electric minivan based on the company's popular Dodge Caravan and Plymouth Voyager models—that could lead to commercial production. The work builds on the development of four concept electric TEVans by Chrysler subsidiary Pentastar Electronics, with support from EPRI, Southern California Edison, and California's South Coast Air Quality Management District. The TEVan's increased performance and styling are expected to appeal to a broad consumer and light fleet van market. Its prototype nickel-iron batteries are lighter and provide more energy than lead-acid.

TEVan Specifications	Range on full charge: >100 miles
Top speed: 65 mph	Recharging: 8 hours on 220-volt outlet
Acceleration: 0 to 50 mph in 14 seconds	Payload: 5 occupants
Batteries: 30 6-volt nickel-iron	Energy consumption: –0.5 kWh per mile

vations that are expected to show up in future-generation EVs, including high-efficiency, variable-speed air conditioning that cuts the range penalty of air conditioning on EVs by as much as half.

In the fleet van market, EVs will perhaps compete most directly with a variety of other alternative-fuel vehicles, including compressed-natural-gas vehicles, of which there are already 30,000 or more (vans and light trucks) operating. Some combined electric and gas utilities also actively promote CNG as a transportation fuel. Conventional gasoline vehicles, particularly heavier trucks and buses, can be retrofitted to burn CNG.

Beyond today's commercial electric service van, each of the Big Three auto companies has an EV development program under way. Chrysler has a team developing prototypes of the TEVan under a two-year agreement with EPRI that could lead to commercial production by the middle of the decade. Chrysler is building on a three-year effort by its subsidiary Pentastar Electronics, with support from EPRI, SCE, and California's South Coast Air Quality Management District. That effort yielded four prototypes of an electric concept version of Chrysler's innovative minivan—three equipped with prototype nickel-iron batteries and one with lead-acid batteries.

With increased specific energy over lead-acid batteries, nickel-iron batteries give the lighter TEVan a range of more than 100 miles—nearly double that of the G-Van, but with only two-thirds the battery weight. The concept TEVan features a 65-mph top speed, 0-to-30-mph acceleration in about 8 seconds, an onboard battery charger, and an automatic battery-watering system.

The TEVan's range, size, and interior appointments make it a versatile five-passenger or 1000-pound light cargo vehicle that is expected to have substantially different market appeal than the G-Van (although the G-Van can be used as a five-passenger vehicle). Chrysler's Dodge Caravan and Plymouth Voyager gasoline models, on which the TEVan is based, account for more than half of the U.S. market for minivans, reported at over 800,000 vehicle sales a year.

In announcing agreement to engineer and produce about a dozen TEVans for testing, officials of both Chrysler and EPRI acknowledged that the commercial availability of economical nickel-iron batteries or other advanced batteries is essential to the TEVan's future as a production EV. "The current state of battery technology has not yet achieved success against two of our greatest technological concerns—initial high cost and limited range," said François Castaing, vice president of vehicle engineering at Chrysler.

Indeed, the energy density, weight, and cost of battery systems—both available and not yet commercial—pose trade-offs that run straight to the bottom line of what makes EVs considerably more expensive today than conventional vehicles. The limited-production G-Vans are costing buyers $50,000 apiece (cargo model, base price), including $7000–$8000 for a lead-acid battery pack that must be replaced about every 30,000 miles. The first several dozen preproduction TEVans will also carry a high price tag. In volume production, experts believe, the price of EVs must be brought within a range that is competitive with gasoline vehicles to appeal to prospective buyers.

Even in high-volume production, nickel-iron batteries are expected to cost more than lead-acid but to last as much as twice as long. EPRI, with support from SCE and other utilities, is sponsoring the development by Eagle-Picher Industries, which made the initial prototypes, of a 500-unit-per-year pilot manufacturing plant for nickel-iron battery packs. Eagle-Picher's Missouri plant could be in operation next year.

Of the Big Three, GM has made the most explicit commitment so far to manufacture EVs in the 1990s. Last March GM confirmed that it will produce a passenger EV much like its Impact concept car in the 1990s, beginning for the California market. The Impact concept vehicle was built for GM by a development team headed by AeroVironment, the California firm of inventor Paul MacCready that also developed the experimental, solar-powered Sunraycer for GM, as well as the record-setting human-powered aircraft Gossamer Albatross and Gossamer Condor.

By integrating numerous design features that boost efficiency and reduce the Impact's aerodynamic drag to half that of production cars, AeroVironment was able to make a lightweight concept vehicle having a projected maximum range of 120 miles at 55 mph and powered by just 850 pounds of lead-acid batteries. (That means the Impact is equivalent in efficiency to a gasoline vehicle that gets 80 miles per gallon.)

GM introduced the Impact to the news media with a videotape that showed it outrunning a Mazda Miata and a Nissan 300ZX. But observers have noted that, in reality, there could be little sustained cruising at the Impact's 75-mph top speed and few of the jackrabbit, 8-second 0-to-60-mph sprints shown on the video if the vehicle was still to have more than a 100-mile range with its present battery pack. When it first revealed details about the Impact, GM said the battery pack should cost about $1500 to replace every 20,000–25,000 miles.

The company says it will convert its Buick Reatta Craft Centre in Lansing, Michigan, to electric car production, which reportedly could begin as early as 1993. GM has formed a new unit of several hundred employees from various divisions to develop and market EVs. While the company has not said what price tag its new electric car will carry, GM's Kenneth Baker says the nation's largest carmaker fully "realizes that the vehicle must be competitive in the retail market."

Meanwhile, Ford announced in April that, beginning next year, it will build a test fleet of up to 100 electric delivery vans modified from British-made Ford Escort vans. These vehicles will be evaluated in fleet use in this country and in Europe. Ford stressed it was not making a commitment to mass-produce the van. "What we're announcing today is that we're in the electric vehicle business, we're in it on an international basis, and we're going to do our homework carefully before embarking on any large-scale production," said John McTague, vice president of technical affairs at Ford.

Ford said that the Escort electric van will be designed for a top speed of 70 mph and a range of 100 miles, using advanced sodium-sulfur batteries. Ford earlier pioneered sodium-sulfur batteries in an experimental electric version of its Aerostar minivan—dubbed ETX-II—that was built under DOE's EV development program. The Escort will also use an alternating-current motor drive Ford first developed for the ETX-II. This motor weighs half as much as the direct-current motors used in other EVs to date and is projected to cost less than half as much.

The few ETX-II models that have been built are powered by prototype sodium-sulfur batteries supplied by both of the principal developers of the technology, Chloride Silent Power of Britain and Europe's ABB Asea Brown Boveri. Sodium-sulfur batteries promise to extend the range of EVs to 150–200 miles.

SCE recently agreed to lease as many as 10 of the Ford Escort vans, beginning in 1993, for test and evaluation. SCE's Schweinberg says the utility is pursuing a similar lease contract with GM for future EVs.

In addition to Detroit's Big Three, there may be other firms, including smaller ones, manufacturing EVs for U.S. sale in the 1990s. Under the L.A. Initiative, Clean Air Transport of Sweden has said it will develop a four-passenger, 150-mile-range hybrid electric car for sale starting next year. Uniq Mobility, a custom vehicle manufacturer in Colorado, says it hopes to make a hybrid electric van for sale under the program. Hybrid vehicles typically employ a small (approximately 10-hp) on-board gasoline-powered engine-generator to supplement and extend battery power and range. In addition to specialty producers, observers say, it is likely that many of the major European and Japanese auto manufacturers could manage to field EVs, which they have been quietly developing, within a short time of the introduction of American-made EVs in the California market.

New directions on the road to EVs

With American carmakers engaged in active EV development programs and a major industry-government consortium for battery R&D coming together, EPRI has been refocusing some of its EV-related activity to better complement the overall effort that is gaining momentum.

Part of this shift involves hybrid electric vehicles, which EPRI and others feel have a significant potential as an interim alternative to advanced batteries for extended driving range. GM has built a hybrid electric van concept vehicle it calls the HX3, and Ford says that some of its demonstration Escort vans will be built as hybrids (with a range of up to 250 miles). Also, both of the small specialty manufacturers with plans to offer com-

General Motors' Impact: An Electric Two-Seater Sports Coupe

GM says that it will convert one of its Michigan factories to begin making, within a few years, an electric passenger car much like the Impact concept car it unveiled in January 1990. The first such vehicle designed from the ground up as a passenger EV, the Impact features advanced engineering, materials, and components but uses conventional lead-acid batteries. The design innovations—including low-resistance, high-pressure tires, very low drag aerodynamics, and two ac front-wheel drive motors—result in a highly efficient EV that in many respects matches the performance of conventional gasoline vehicles.

Impact Specifications	Range on full charge: 120 miles at 55 mph
Top speed: 75 mph	Recharging: 2 hours on 220-volt outlet
Acceleration: 0 to 60 mph in 8 seconds	Payload: 2 occupants
Batteries: 32 10-volt high-power lead-acid	Energy consumption: 0.1 kWh per mile

EVs From Ford Motor for Demonstration and Development

Ford Motor Company plans to produce, beginning next year, a demonstration fleet of 70 to 100 electric Escort compact vans for fleet use and evaluation. The vans will incorporate many of the features Ford pioneered in EV development work supported by the U.S. Department of Energy. These include advanced sodium-sulfur batteries for extended EV driving range and lighter, less-expensive ac drivetrains for vehicle propulsion. One product of the DOE-sponsored work was the ETX-II, a modified Ford Aerostar minivan. Ford has not announced plans to mass-produce the electric Aerostar, but it is continuing R&D with DOE support to develop modular power train components for several vehicles, including the Aerostar.

Escort Van Specification Targets	Range on full charge: 100 miles
Top speed: 70–75 mph	Recharging: 6 hours on 220-volt outlet
Acceleration: 0 to 50 mph in 14 seconds	Payload: 750–1000 pounds total; 2 occupants
Batteries: sodium-sulfur	Energy consumption: not available

ETX-II Specifications	Range on full charge: 100 miles
Top speed: 65 mph	Recharging: ~8 hours on 220-volt outlet
Acceleration: 0 to 50 mph in 20 seconds	Payload: 1100 pounds total; 7 occupants
Batteries: sodium-sulfur	Energy consumption: not available

mercial EVs under the L.A. Initiative have said their vehicles will be hybrids. "Hybrids are being looked at by all the manufacturers because they are a way to get range as close as possible to that of gasoline vehicles from the early production EVs without waiting for advanced batteries," says Gary Purcell. A possible design might feature computer-programmed operation to ensure optimum battery use and minimum operating cost for a given trip.

EPRI has contracted with McKee Engineering of Chicago, Illinois, to develop a prototype hybrid version of the G-Van that—at about 120 miles—is designed for twice the range of the G-Van running on batteries alone. A 6.5-kW, 10-hp onboard generator such as that used in recreational vehicles would provide supplemental dc motor power when needed to slow the rate of battery discharge for longer range. If tests of the prototype in fleet use next year go well, EPRI could pursue commercial production of an extended-range G-Van by Vehma International in 1993.

Because they are more complex than pure EVs, hybrids may cost more to engineer and manufacture. Their engine-generators will probably disqualify them as zero-emission vehicles, but California air quality regulators are said to be drafting provisions to accommodate hybrids as very low emission transition vehicles. Equipped with electrically heated catalytic converters and operated at constant speed, the generators can be optimized for very low emissions levels compared with conventional gasoline cars, researchers say.

In addition to stretching the range of today's EVs, EPRI is leading utility industry initiatives to organize and lay the groundwork for certain aspects of EV infrastructure. EPRI heads a working committee of utility and automaker representatives that is scoping out the issues on such matters as the deployment of EV recharging systems and technical standards for those systems. Utilities are expected to spearhead the development and deployment of different recharging systems, along with customer service, incentive electricity pricing, and promotion for EVs.

A step in the direction of establishing an EV infrastructure—an umbrella term for most service and maintenance requirements—is to set up utility-based EV service centers. "These are expected to be an interim solution for providing infrastructure until the EV market is large enough that the auto companies will set up to provide it themselves," says Jim Janasik, an EPRI project manager.

Utility EV service centers will become focal points for parts and maintenance, training, and recharging for what are expected to be mainly fleet EVs. EPRI is cosponsoring the startup of three centers this summer in the territories of Consolidated Edison in New York City, Houston Lighting & Power, and the Sacramento Municipal Utility District. Each of the utilities has purchased a number of G-Vans for its service fleet, and additional G-Vans will be placed at the centers by EPRI for demonstration and staff training. EPRI managers hope to have two more utility EV service centers operating by next year and as many as eight in 1993.

At this writing many aspects and details of EV infrastructure are yet to be defined, and there are questions among both utility and auto industry personnel, who will be working together in many cases to set common technical standards. Portable recharging units for the G-Van are essentially electrically isolated transformers that convert utility ac power to dc for batteries. They are quite heavy and represent a considerable expense in themselves. Much lighter, on-board electronic chargers, such as those installed in the TEVan concept vehicles, are the likely future course.

Because the possibilities for EV service and recharging are so numerous and are still undefined at this stage, questions come much easier than clear answers. Beyond home-based charging in the garage, what about public charging facilities? In 1931, the city of Chicago boasted 36 downtown locations for EV recharging. Will modern charging setups—perhaps operated by coin or by bank debit card—become common sites in public garages and parking lots or at street curbs?

"The key considerations have to be safety and convenience," says Roland Risser, an R&D project manager for Pacific Gas and Electric. "We need hardware that is easy to use and almost impossible to misuse or abuse. Also, while we would like all EVs to be recharged overnight at the most preferred off-peak period, in reality we know it is unlikely that this will exclusively be the time customers recharge EVs." The northern and central California utility is already discussing the prospects for installing recharging facilities in parking lots owned by the Bay Area Rapid Transit system to serve commuters' EVs.

Risser readily acknowledges that the peak/off-peak question really becomes an issue only once there are substantial numbers of EVs on the road, "but we need to work through the technical implications to a great extent now." He says PG&E has hopes for applying computer power and electronics to make a smart charging timer—one that could be programmed to avoid certain peak demand periods yet selectively recharge an EV throughout the course of a day (or night).

At its San Ramon Engineering Research Center, PG&E has built, with EPRI support, a prototype magnetic induction EV-recharging system that, if developed, could become a quick and convenient alternative to the plug-in-and-wait approach. EVs could be built with an underplate that would receive current by magnetic induction when the vehicle was parked over a matching groundplate recharger. Such an arrangement might offer faster charging and greater safety and be virtually vandal-proof.

"We can see that some development work needs to take place, and we feel strongly that the auto, battery, chemical, and utility industries are going to have to work together, as well as focus on their own pieces of the future EV market, to make sure we are prepared to meet the demands of the market," says Norman Bryan, PG&E's vice president for clean air vehicles. "We see EVs as a very favorable load for our system and a viable new market for the utility industry that offers tremendous environmental benefit. We think EVs have a very promising future, and we are planning and developing an appropriate utility infrastructure to meet the future demand."

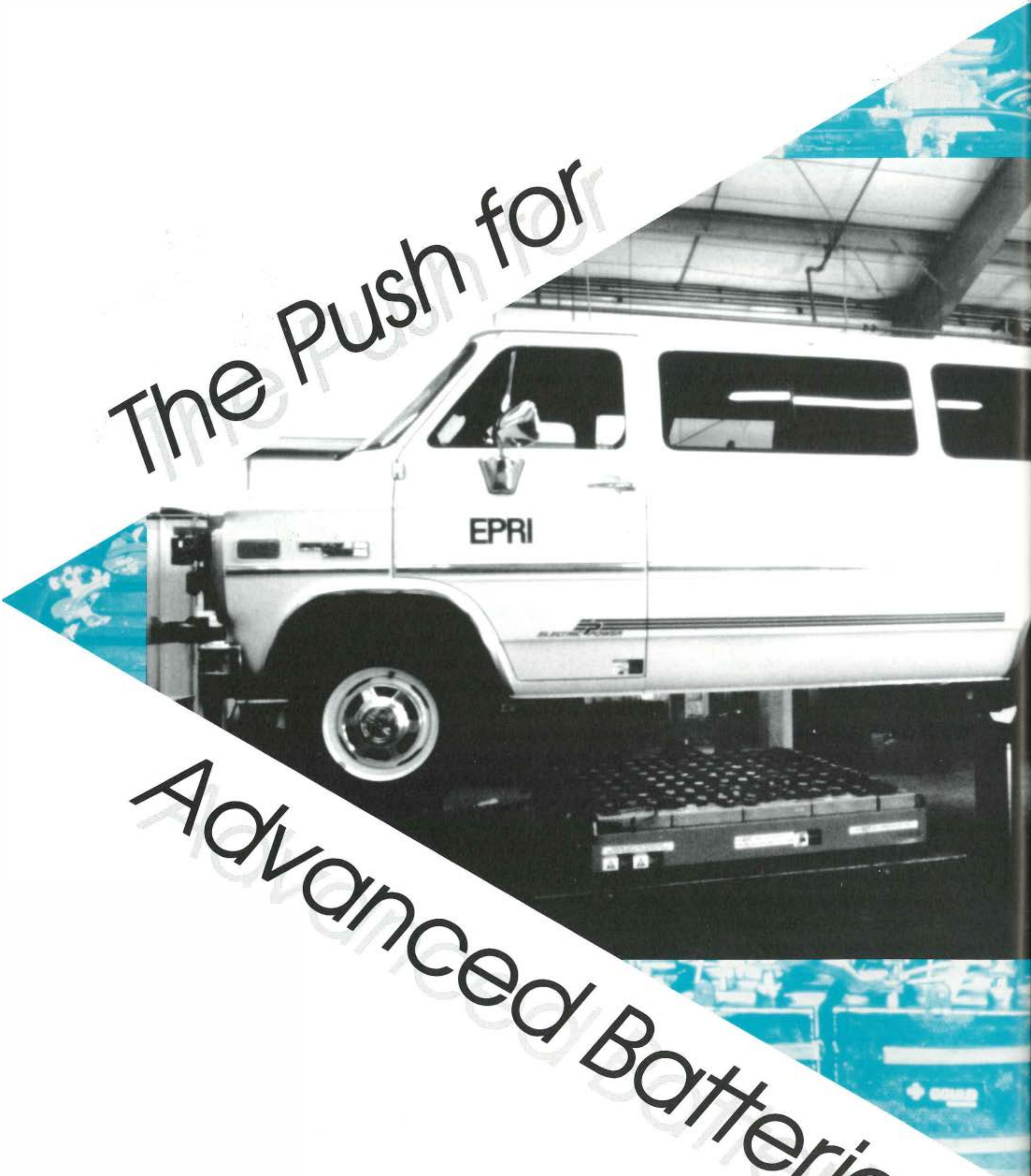
A vision for the future

Says Arnold Fickett, vice president for customer systems at EPRI, "It's very important to look beyond today's technology and realize that if Detroit really gets involved and develops and markets EVs the way they have successfully marketed conventional vehicles, and if the public responds the way we think they will, there is a tremendous opportunity for electric transportation to begin to address some very real problems in this country. But the real key for our utility members to understand is that the electric vehicle advantage is an electric utility advantage. The visionaries of our industry can see the great potential in the future of EVs.

"At EPRI we're excited about the advanced battery consortium and our role in it because the future of the electric vehicle is completely dependent on the performance and cost of batteries. We still have a ways to go before we will see the kinds of batteries that can make EVs succeed, but we believe the consortium is the key to achieving success." ■

This article was written by Taylor Moore. Technical information was provided by Jack Guy, Lawrence O'Connell, and Gary Purcell, Customer Systems Division.

The Push for Advanced Batteries



Thomas Edison and Charles Steinmetz—the greatest electrical geniuses of their time—are said to have tried and given up on developing high-power, long-life, inexpensive batteries that would enable EVs to squarely compete with gasoline-powered vehicles. Then, as now, the only commercially available battery technology suitable for EVs was lead-acid, and though modern versions may last longer and cost somewhat less than those at the turn of the century, the performance and range afforded by lead-acid batteries have not improved much.

Battery makers and other technology companies (including several with support from EPRI) have been working on an array of new materials and types of batteries for over 25 years. But in the absence of established market demand for such advanced batteries, those efforts have not been sufficient to overcome the technical, manufacturing, and economic barriers to a truly practical EV battery. Many interested parties are counting on the recently formed U.S. Advanced Battery Consortium to marshal technical and financial resources for a focused, collaborative R&D program to identify and develop several mid- and longer-term EV battery technologies later in this decade. Some of the ongoing battery R&D sponsored by the Department of Energy and EPRI could become part of the USABC program.

From more than half a dozen candidate battery technologies, the apparent consensus among USABC sponsors is to focus on demonstrating the feasibility and capability of processing and producing sodium-sulfur batteries at pilot plant scale by 1994. By then, the consortium also wants to have demonstrated, with a full-size experimental battery, the feasibility of designing a plant to manufacture the even more advanced lithium–metal disulfide and lithium-polymer batteries.

THE STORY IN BRIEF

The widespread success of electric vehicles depends primarily on the development of advanced batteries that can deliver improved driving range and performance. While the earliest EVs on the road are likely to operate on large packs of conventional lead-acid batteries, researchers are exploring advanced batteries based on sodium-sulfur, lithium–metal sulfide, and even more exotic electrochemical combinations; the goal is to commercialize the most successful of these later in the decade.

Mature batteries

Today's lead-acid battery packs limit an EV such as the G-Van to about 60 miles on an 8-hour charge. With advanced design and materials for maximum aerodynamic efficiency, General Motors' Impact concept car manages to stretch the projected range of its one-third-lighter battery pack to 120 miles. A nickel-iron battery offers one and a half to two times the vehicle range of lead-acid, but at an increased cost. And such a battery is not expected to be commercially available until 1993 or 1994.

According to Robert Swaroop, project manager for EV battery systems at EPRI, "Battery cycle life is the key trade-off with other performance factors." The benchmark lead-acid batteries of today will last for about 30,000 miles with deep discharging cycles and even longer with light use and frequent opportunity charging. The cycle life of today's lead-acid batteries is about 750. A battery with a design target of 1000 operating cycles might power an EV for 60,000 miles before requiring replacement. All of the advanced technologies offer significantly greater performance over lead-acid in terms of energy and power, and the best projections of operating life for most of them also exceed lead-acid's life.

Another key consideration for EV batteries is maintenance. Lead-acid batteries can be made maintenance-free, like those found today in many gasoline vehicles, and such batteries may soon become available for near-term EV application. EPRI is testing maintenance-free, sealed lead-acid batteries from the German manufacturer Sonnenschein at Argonne National Laboratory. Nickel-iron batteries must include a system for regular watering and the removal of hydrogen gas generated during recharging. There is a novel but promising bipolar version of a sealed lead-acid battery under development by ENSCI, Inc., with support from the Jet Propulsion Laboratory and Southern California Edison. Compared with nickel-iron, it offers improved efficiency and performance.

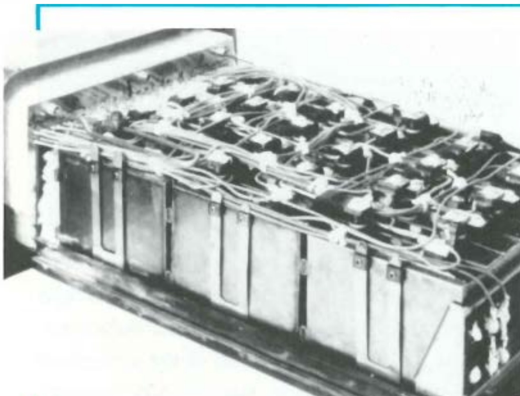
In addition to lead-acid and nickel-iron, relatively mature battery technologies include nickel-cadmium, on which Japanese and European manufacturers are known to be working. A nickel-cadmium unit made by the French battery maker SAFT is under test at Argonne, but such batteries are expected to remain prohibitively expensive for EV application, and there are disposal issues associated with cadmium's toxicity.

Developmental batteries

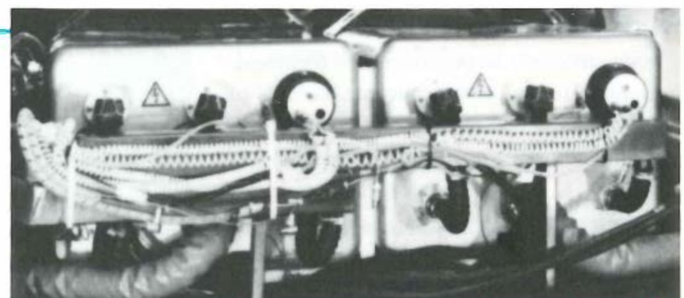
To achieve significant gains in EV range, batteries must be made from much more energetic electrode materials than lead or iron. The electrochemical couples of sodium and sulfur (Na/S) and lithium-aluminum and iron sulfide ($LiAl/FeS_x$) have the desired specific energy, but both must operate at high temperatures.

How Advanced Battery Technologies Compare With Lead-Acid

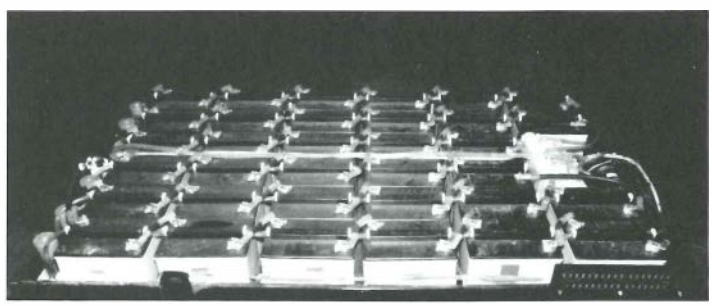
Researchers state the potential vehicle range and acceleration power of advanced battery systems under development in relative terms to today's conventional lead-acid batteries. Depending on the vehicle, the number of batteries it is designed to carry, and the driving duty, lead-acid batteries can power EVs for 50–100 miles on a single charge and can provide acceleration that approaches that of conventional gasoline vehicles. At high-volume production, some of the advanced battery technologies are expected to approach lead-acid batteries in cost. Numerous test EVs have already run on prototype nickel-iron and sodium-sulfur batteries, which are now at the pilot plant stage of manufacturing development. Multicell modules of lithium–iron monosulfide batteries have been made, but researchers say it is the disulfide version of the technology—still at laboratory scale—that offers the potential for an EV driving range of over 300 miles. Potentially lighter-weight, solid-state lithium-polymer batteries are also under development.



Lithium–iron monosulfide subbattery pack



Developmental sodium-sulfur battery pack



Nickel-iron battery pack

Lead-acid battery such as used in the G-Van

	Relative Energy Capacity (range)	Relative Peak Power	Availability
Lead-acid	1.0	1.0	Now
Nickel-iron	1.5×	1.3×	1993
Sodium-sulfur	2–3×	2.5×	1995–2000
Lithium–iron monosulfide	2–3×	1.8×	1995–2000
Lithium–iron disulfide	3–5×	6–7×	2000+
Lithium-polymer	3–5×	3–4×	2000+

Researchers believe that Na/S batteries offer the best hope of providing EVs a potential range of 150–175 miles by the end of this decade. Developed originally by General Electric in the 1960s and later, in the 1970s, by Ford Motor Company, the Na/S battery uses a ceramic beta-alumina electrolyte tube with sodium negative and molten sulfur positive electrodes on opposite sides within a sealed, insulated container. The battery pack itself is further insulated, since Na/S modules operate at 350–380°C (662–716°F). Because of both the operating temperature and sodium's reactivity, the batteries must be designed with a high degree of ruggedness and safety.

The two principal developers over the last two decades have been Britain's Chloride Silent Power, Ltd., and the Swedish-Swiss conglomerate ABB Asea Brown Boveri (including its Canadian subsidiary, Powerplex). ABB has a pilot plant in Germany, and Chloride has formed a joint venture with the German utility RWE for a pilot plant in Britain to manufacture Na/S batteries.

Several test vehicles, including experimental Ford electric vans and a fleet of German passenger cars, have been running on batteries from these suppliers. DOE and EPRI have supported development work at Chloride and are testing Na/S batteries at Argonne and the Electric Vehicle Test Facility in Chattanooga, Tennessee.

Although they currently cost at least four times as much to produce as nickel-iron batteries, Na/S batteries have low projected volume production costs—thanks to inexpensive materials—and a long projected service life. Only ABB's battery has yet demonstrated over 1000 operating cycles for full-size modules, however.

Argonne National Laboratory originally developed the $LiAl/FeS_x$ system in the early 1970s. Using more-expensive but nonreactive materials, the battery's key advantage over Na/S is greater safety. It uses a porous magnesium oxide or boron nitride separator and a potassium and lithium chloride electrolyte, and it maintains the electrodes at an operating temperature of 400–450°C (750–842°F). SAFT America, a subsidiary of the French battery company, is the leading developer of this technology today and is being funded by DOE and EPRI to scale up the Argonne technology, which has received considerably less R&D support than Na/S.

Researchers are particularly interested in a disulfide version of the $LiAl/FeS_x$ battery for its potential to boost the range of EVs to over 300 miles. "But that's at least 12 years away," says EPRI's Robert Swaroop. "First we have to solve the problems of lithium monosulfide batteries, which today are cycle life and calendar lifetime." Lithium batteries are widely used in a number of special military applications, "but it will be tough to make them big and powerful enough for EVs," adds Swaroop. Researchers hope to see a few proof-of-concept lithium monosulfide EV batteries by 1993 or 1994.

EV batteries for the long term

Perhaps the ultimate, 300-mile-plus, rechargeable EV power supply envisioned by some researchers would be the lithium-polymer battery, operating from ambient temperature to 120°C (248°F) and easily manufactured in versatile thin films usable in a variety of configurations. Recent advances in the new materials science of conducting polymers are incorporated in the form of a plastic-like solid electrolyte. Such solid-state batteries are at a very early stage of development and are presently being made in small sizes and low power ratings.

One of the leading efforts on lithium-polymer batteries is a joint venture recently formed between Canada's Hydro Québec and Japan's Yuasa Battery Company to develop the technology to full scale. A small, laboratory-scale version of the battery has recorded more than 500 operating cycles over two years. Swaroop says a major challenge in scaling up lithium-polymer batteries is to find a way to dissipate the heat generated during charging and discharging without causing long-term damage to the polymer electrolyte. Other groups in Britain, Japan, and the United States are working on lithium-polymer technologies. EPRI supports a small part of some of this work in connection with its long-term R&D program for EV batteries. ■

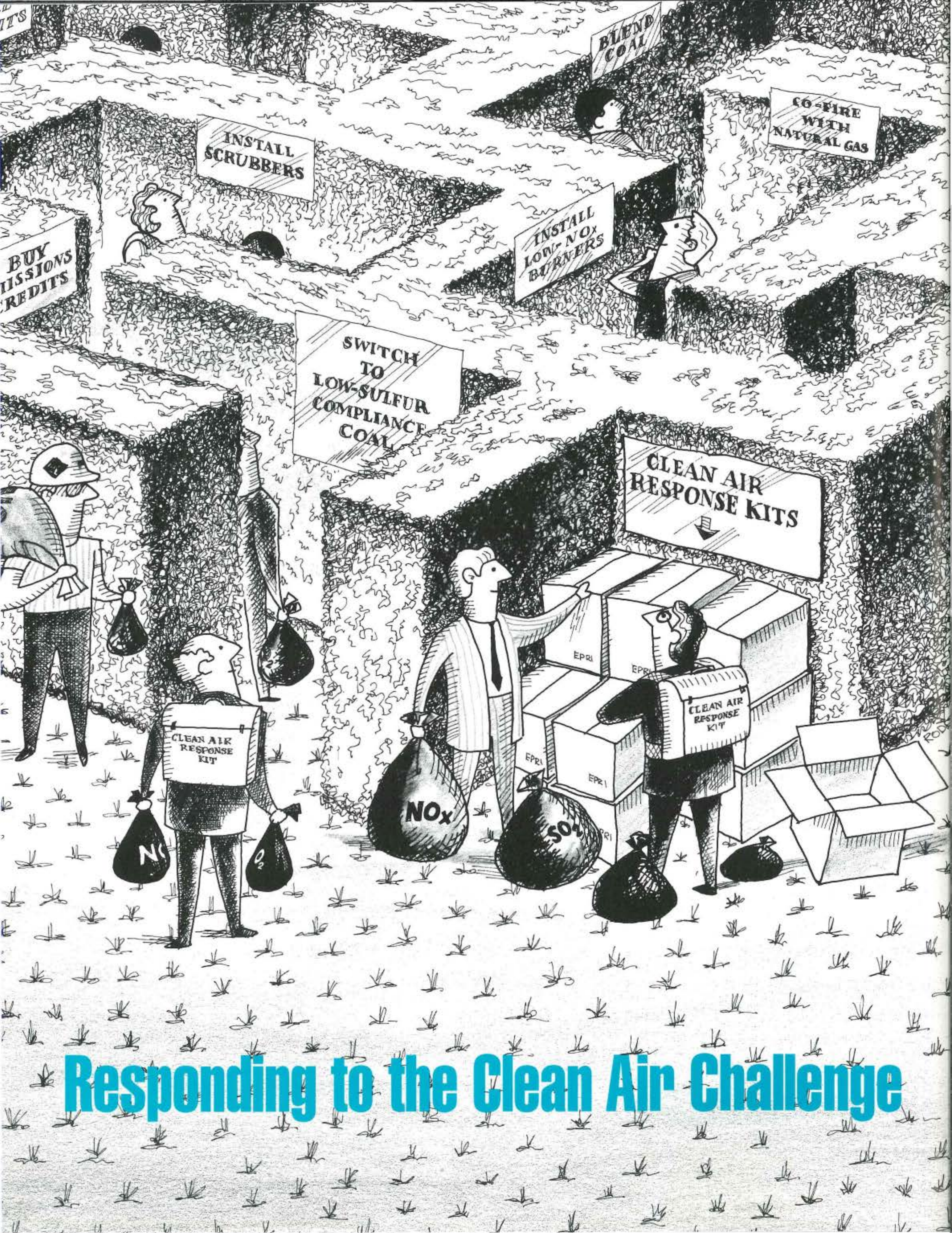
R&D Consortium for EV Batteries of the Future

U.S. automakers Chrysler Corporation, Ford Motor Company, and General Motors Corporation have formed the U.S. Advanced Battery Consortium as a collaborative R&D venture to identify and develop the most promising advanced battery technologies for future electric vehicles. The USABC is soliciting support from the government and the electric utility industry for what it hopes will become a $100-million-a-year effort by 1993. The U.S. Department of Energy is expected to provide a major portion of the program's funding support. EPRI expects to support the USABC and participate in the research consortium on behalf of electric utilities through a cooperative agreement.

USABC UNITED STATES ADVANCED BATTERY CONSORTIUM

This article was written by Taylor Moore. Technical information was provided by Robert Swaroop, Customer Systems Division.

Responding to the Clean Air Challenge



When President Bush signed the revised Clean Air Act into law late last year, the Southern Company was prepared. A 20-member clean air team and an executive board had been hammering out compliance plans for nearly one year. On November 15, when the amendments became law, the utility holding company had its strategic options in place. Within another two weeks, it was able to fine-tune the plan.

Like other electric utilities, the Southern Company didn't want to take any chances. Compliance experts at the holding company reasoned that having plans in place early would give them an advantage in the industrywide scramble for equipment, fuel, and services required to implement compliance strategies. Another incentive was to initiate communication early with the public utility commissions in the company's four service states. The fact is, the company's stockholders just emerged from a difficult five-year period after the utility was not able to recover all expenses on a large nuclear plant. "Obviously we don't want to go through that experience again," says Jim Stevenson, manager of Clean Air Act compliance at the holding company, which expects to spend between $2 billion and $3 billion cutting emissions.

With the industry facing its biggest capital expenses since the nuclear projects of the 1970s, utilities across the country are similarly prepared. Many have established multidisciplinary teams to develop strategies for least-cost compliance. While some, like Southern Company, already have plans in place, others are still developing their options. Some don't expect to finish crafting their plans until late summer.

The 1990 Clean Air Act Amendments ended a decade-long debate over air pollution rules. Representing the first tightening of federal air standards in 13 years, the new law aims to reduce acid rain and urban smog. In the utility industry, it re-

THE STORY IN BRIEF

The 1990 Clean Air Act Amendments pose the utility industry a great challenge—to significantly reduce SO_2 and NO_x emissions while continuing to produce electricity cost-effectively. More stringent than previous air pollution laws, the revised act will result in large capital expenses, with industrywide compliance costs expected to run $4 billion to $7 billion annually. Fortunately, the new law does offer some flexibility in choosing approaches for least-cost compliance. In addition to scrubbing, fuel switching, and advanced technology options, utilities will be able to engage in open-market purchase and trading of SO_2 emissions allowances. As utilities across the country work to develop the best compliance strategies for their individual systems, EPRI is helping to guide them through the compliance maze with a Clean Air Response Kit containing tools for technical analysis and decision making.

quires power plants to halve their sulfur dioxide (SO_2) emissions and to cut their nitrogen oxide (NO_x) emissions 30%. The reduction in SO_2 emissions, which reflects a level that is 10 million tons per year below 1980 emissions levels, is to be accomplished in two phases. Units at 110 plants must comply by 1995 to 1997, while all other utility sources have until 2000. After this time, total SO_2 emissions from all utility plants are to be capped at 8.9 million tons per year. This means utilities must offset emissions produced by any new generation. The Clean Air Act does not separate utilities' NO_x emissions from those of industry, automobiles, and other sources. But according to EPRI's calculations, the act will cause utilities to reduce their NO_x emissions by about 2 million tons per year below the emissions level projected for the year 2000 without controls.

Utilities will have some flexibility in choosing approaches to effect these reductions. For SO_2, the top options are retrofitting plants with flue gas scrubbers and switching to low-sulfur coal use. Modifying the coal combustion process is the most favored option for NO_x control.

SO_2 compliance will be regulated through an emissions allowance (EA) system, in which one EA represents the right to emit 1 ton of sulfur dioxide in the year the EA is awarded or in a later year. Annually, the Environmental Protection Agency (EPA) will issue utility units a certain number of allowances based in part on the units' past emissions. New units—with the exception of some that are already in the development phase—will receive no allowances. To encourage least-cost compliance, the legislation includes a provision for the purchase and open-market trading of EAs. This means utilities can choose to comply by cutting emissions or by buying extra allowances from another source. If a utility can reduce emissions beyond compliance level at a cost lower than another utility's cost, it may choose to "overscrub" and market or bank its extra allowances. Continuous emissions monitors (CEMs), required by 1993, will continuously track emissions. A utility's EAs must be sufficient to cover its measured emissions, or the utility will face penalties, including stiff fines, reductions in emissions allowed the following year, and even imprisonment of its executives.

According to utility industry estimates, the cost of SO_2 emissions compliance will run from $4 billion to $6 billion annually. The cost of NO_x compliance is expected to be an additional $0.5 billion to $1.0 billion annually. In addition, there are EPA studies under way to determine whether the industry should be regulated for hazardous air pollutants known as air toxics. This could add another $8 billion annually to the industry's tab.

The legislation comes at a challenging time for the utility industry. Many companies are still feeling the impact of inadequate cost recovery on their nuclear projects. Others have gone through downsizing and restructuring during the increased competition of recent years. Many utilities in certain regions of the country are nearing their maximum generating capacity. With the cap on SO_2 emissions, future generation planning will become much more complicated. In the meantime, uncertainties linger in the markets—for fuel, equipment, and services—that utilities will depend on for compliance. And there are numerous questions about the law itself, for regulations governing the details of compliance have not yet been written.

Other types of challenges are emerging as well. For instance, both EPRI's and the EPA's preliminary calculations indicate that the formulas the EPA used to figure allowance estimates for SO_2 fall about 8% short of achieving the cap specified in the legislation. As a result, it appears there will be about 8% fewer allowances doled out than utilities had expected.

"I think the industry's in for a learning process," says Jeremy Platt, senior project manager in engineering and economic evaluations at EPRI. "We're all going to learn rapidly from ourselves and through our industry forums."

A challenge unlike any other

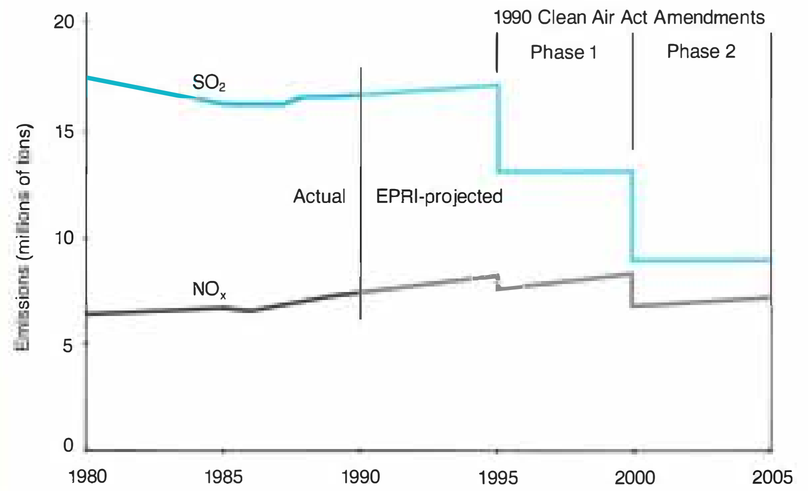
The new amendments raise a challenge unlike any the industry has faced before. Aside from being more stringent than previous legislation, they affect virtually all existing utility plants. Previous versions of the Clean Air Act affected primarily new plants; existing plants were exempted unless located in areas exceeding the limits of national health-based ambient air standards. Also new is the emissions cap for SO_2 in the post-2000 period. In fact, aside from a similar cap implemented in Canada in 1985, there has been virtually no experience with such an emissions cap in other countries with SO_2 control.

The nature of the limitation also is different under the new law. Compliance under previous standards was based on average emissions over a 30-day period. Now emissions are to be calculated on a tons-per-year basis. This gives utilities more flexibility in developing compliance plans. Further increasing flexibility is the provision for emissions allowance trading. While EA trading has existed to some extent for 14 years in the industry, it has taken place only in some so-called nonattainment regions. The new amendments will create a nationwide market for EAs, which revolutionizes the nature of utility compliance planning. In the past, regulations reflected a command-and-control approach, in which regulators were to dictate details on how utilities must reduce pollution. By contrast, the allowance trading system reflects a market-based approach, emphasizing the freedom of companies to choose the most cost-effective methods of compliance.

All these differences suggest that compliance planning is no longer a one-time engineering challenge. It is an ongoing financial planning question. It requires a broader-based planning effort involving a

Utility Emissions Trends

The new Clean Air Act requires utilities to halve their 1980 SO_2 emissions level and to cut NO_x emissions 30% from the level projected for the year 2000 without controls. The two-phase reduction for SO_2 caps industrywide emissions at 8.9 million tons per year in 2000. The act does not call for a cap on NO_x emissions, which are more difficult to monitor. In fact, the EPA is still working on some critical issues regarding NO_x emissions.



wide spectrum of expertise. "The legislation calls for utilities to understand the market in a way they haven't had to before," says Ian Torrens, director of EPRI's Environmental Control Systems Department. "They have to learn how the allowance system is going to work. They need to know what their neighbors are doing to comply with the legislation. And they need to get a good overall picture of what the industry is doing. It's a bit like playing Wall Street or the Chicago Commodity Exchange."

One result of all these changes has been the reorganization of utility staffs, including the formation of Clean Air Act compliance teams. These multidisciplinary teams involve groups of people that in some cases have never worked together before. "This is not an issue that utilities have been shunting to their engineering staffs," says Jim Fortune, program manager for engineering and economic evaluations at EPRI. "It is not an engineering decision. It's a business decision, and many facets of the corporation are going to be affected by it." Fortune says the most effective compliance teams have been those that involve executive or senior management attention.

Some of these teams have only recently formed. Southern Company's is among the more seasoned. Much like other utilities, the holding company had been analyzing the impact of potential acid rain legislation since the mid-1980s. With the help of its legislative liaison office in Washington, D.C., Southern Company was able to keep abreast of possible changes. In 1989 it became clear that legislation was likely to pass within 12 months. This realization spurred the establishment of the 20-member compliance team in December 1989. At the same time, the executive project board was created. Stevenson was named project manager and assigned full-time to Clean Air Act compliance.

The compliance team was made up of experts from a variety of areas, including fuel, bulk power marketing, environmental affairs, technology assessment, engineering, finance, and strategic planning. It met formally once every two months, but its members worked together continuously. The executive board was made up of senior-level representatives from each of the five operating companies and also from the service company. Stevenson reported to them quarterly. By mid-year 1990, the company had the first version of its compliance plan mapped out. The document continued to evolve as legislative changes emerged and utility experts came up with new findings.

"What we think we've gained from getting out in front is flexibility in compliance and deciding between alternatives," Stevenson says. "We didn't want to end up in a situation where we had no choices." The company's final plan includes three options for compliance, with EA trading accounting for the key differences between them. "Some people say we don't know exactly what we're doing. And that's right. We don't know—exactly," Stevenson says. "But that's the point. We're very fortunate to be in what we consider a flexible strategy position." Early this year the company appointed a director to implement compliance. Stevenson's duties changed too. He is now also responsible for allowance trading.

Tough decisions

Just what kinds of strategies are clean air teams developing for utilities? Will they switch coals, go with retrofit technologies, or use some combination of the two? What role will natural gas play in their plans? What about allowance trading? At this point utilities are tight-lipped about their intentions, and for good reason. Any leaks on compliance plans could turn a least-cost strategy into a much more expensive option. In the words of Steve Jenkins, manager of regulatory affairs at Tampa Electric, "We're all in competition, and my ratepayers will benefit more if I tell everybody nothing."

Many utilities, for instance, have coal contracts coming up for renegotiation. Informing a coal supplier about an intended plan could lose a utility some negotiating room. The same goes for fuel transportation services, which generally are the single largest component of coal switching costs. Likewise, if a scrubber manufacturer knows a utility intends to scrub, it may be able to charge more for its equipment. "There's a possibility for this to be a very competitive Machiavellian market among all players," Platt says. "Utilities need as many arrows in their quiver as possible to promote competition."

In the meantime, just about every piece of the compliance puzzle is riddled with uncertainty. The actions of the entire industry within such a short timeframe will set off a flurry of activity in markets for fuel, technology, and engineering and construction services. "I think we're in for a bouncy ride in all of these markets," Platt says. In the realm of fuels, there are concerns about reserves and about prices of coal and natural gas. With equipment, there's a concern about bottlenecks and quality, given the relatively small number of suppliers available to meet the anticipated tidal wave of demand. Another fear is that engineering and construction services will be strained. In addition to the demand from utilities, there will be some pressure from the petroleum industry, which must modify its refineries to comply with other aspects of the new law. Simultaneously, both utility and nonutility generators may be soliciting the same services to build new capacity.

But at this time the greatest uncertainty in the compliance puzzle is the allowance trading element. Never before has a brand-new national market been created for such a heavily regulated industry, experts say. This poses a curious challenge. As Jenkins describes it, "To encourage free market trading in a regulated industry is almost an oxymoron." Economists and others will be observing closely.

Emissions trading in the industry was introduced in 1976 through the EPA's ambient air quality program. Already NO_x, SO_2, and particulates have been traded. This trading has occurred only in regions that exceed air quality standards, including Los Angeles, San Francisco, and Baltimore. Nevertheless, the concept has saved money. According to John Palmisano, president of AER*X, an environmental consulting and emissions brokerage firm, existing emissions trading policies have saved utilities at least $1 billion.

The trading element is intended to encourage least-cost compliance. The idea is that if one company can remove a ton of SO_2 at its plant more cheaply than can another company at its plant, then the ton should be removed in the cheaper place. The utility that overcomplies can sell its excess allowances to the other utility, so emissions are reduced at the lowest overall possible cost. One utility may consider the option of installing a scrubber that removes 50,000 tons of SO_2 annually at a cost of $30 million a year. If EAs are trading at $400 per ton, the utility could save $10 million by purchasing allowances instead. Naturally, the market price of the allowances will determine the role that trading will play in utilities' compliance plans. At this time, however, this factor is unknown. Most experts agree that EAs will be worth significantly more in Phase 2 than in Phase 1. Estimates typically fall between $300 and $600 per ton for the first phase and between $400 and $1200 per ton for the second phase.

EA trading can occur on several levels. It certainly will take place between units within one utility system. It could also occur between members of a utility holding company. And it could happen between unrelated utility companies. It could even take place in the form of bulk power exchanges, in which one utility simply generates power for another. There is also a possibility that equipment manufacturers or coal suppliers could enter the picture, using the allowances to "sweeten the pot" for their products.

Utilities are expected to proceed cautiously with this new idea, at least initially. Experts say they will overcontrol in the early stages of compliance, not just because of the uncertainties of the EA market, but also because of the post-2000 cap and the fact that the incremental cost of increasing SO_2 removal from 90% to 95% is relatively small. All of this will gain them extra EAs. To help get the trading going, the legislation directs the EPA to take 2.8% of the EAs away from each Phase 1 unit. These will be placed in an auction pool. Utilities in need of these allowances may find themselves going back to the pool and bidding for what had been their own EAs. The auction pool also will help ensure that allowances are available for independent power producers (IPPs). Palmisano predicts the market will soon heat up. He expects at least one transaction in 1991 and at least five transactions by 1993. Utilities have been encouraged to save money by trading without the services of a broker. Nevertheless, Palmisano expects business to boom, spawning numerous competitors for his firm.

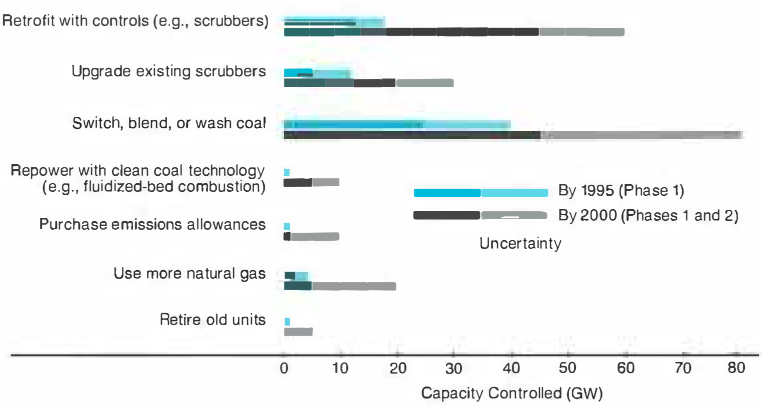
One concern frequently raised is the possibility that utilities will hoard allowances, banking loads of them for future use. But as Victor Niemeyer of EPRI's Environment Division points out, hoarding is only going to be expensive for utilities. "Those allowances are not cheap," he says. "They cost utilities a lot. And there's an opportunity cost of revenue they could have made by selling them."

Regulators challenged too

Utilities aren't the only ones being challenged by the new law. Public utility commissions across the country are grappling with a number of sticky issues it raises. And as Jenkins points out, their role could significantly alter the impact of the legislation. "Regardless of what the act says, the final authority in how our business will be impacted by the Clean Air Act Amendments of 1990 will be determined by the public utility commissions

Options for SO_2 Removal

The new Clean Air Act allows some flexibility in how utilities will reduce their emissions. According to EPRI's projections, the choice of SO_2 removal is likely to be similar to the pattern shown in this graph. Scrubbers are expected to play the biggest role (in terms of tons of SO_2 removed), in part because they often are the most cost-effective way to remove large quantities of SO_2 and because the legislation offers incentive to scrub rather than switch coals in Phase 1. While switching cannot achieve as high an SO_2 removal level, it is attractive because it does not require a great capital expense. Options for reducing NO_x emissions are more limited; in most cases, utilities are expected to install low-NO_x burners.



in our respective states," he says. "The commissions hold our fate." One Florida commissioner has already announced his intention to limit out-of-state EA trading. The concern is that Florida, a rapidly growing state, will need its allowances to accommodate future growth. Others argue that such restrictions will inhibit the effectiveness of the legislation.

But EA trading is only one part of the bigger regulatory picture. After all, it is the PUCs that will determine how both ratepayers and shareholders are affected. Policies must be adopted on such issues as how power pools will be treated, how IPPs will be handled, and how conservation measures will be dealt with. "This is going to be a huge one to address," says William A. Badger, president of the National Association of Regulatory Utility Commissioners (NARUC) and a member of the Maryland commission. "I think commissioners are going to find themselves confronted with some very difficult decisions. There are going to be enormous dollar sums associated with implementing this Clean Air Act. I'm not quite sure the public fully realizes the very significant increases they're going to be called on to support as a result of this."

A number of utilities have already begun talking with their commissioners. Badger describes such early communication as vital to the success of compliance plans. He advises utilities and their commissioners to work together on issues like buying and selling allowances and overcontrol of SO_2 before plans are implemented. One of five commissioners on the EPA's Acid Rain Advisory Committee (ARAC), Badger says he has been passing the information he receives on to utilities under his jurisdiction. "I tell everybody that we're all going to school on this. I think we all need to have as much advice and exchange of information as possible."

ARAC was established to advise the EPA in developing the regulations that will detail how utilities are to comply with the new law. The group has 44 members—including representatives from utilities, coal companies, environmental groups, IPPs, and financial institutions. Of particular concern at this stage is how trading will take place and how the 3.5 million bonus allowances for Phase 1 units—offered as an incentive for utilities to scrub rather than to switch coals—will be distributed. The bulk of the EPA's regulations are to be written by next spring. Others will not be issued for a number of years.

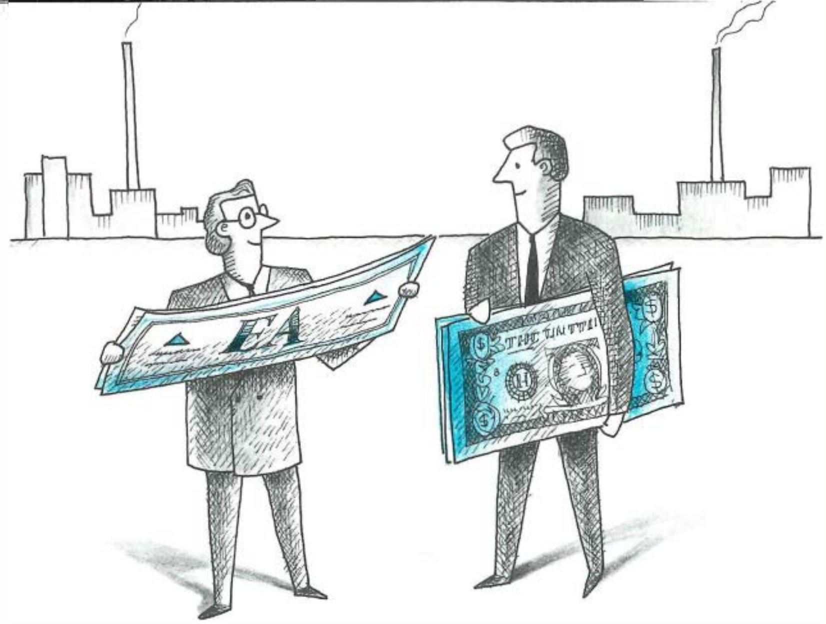
Badger says the PUCs, like utilities, want to avoid a confrontational role. In fact, he is recommending that NARUC adopt an official policy that would significantly alter the prudency review process. Reviews of major new generating projects would take place up front, before a utility's decision is final. Reviews would continue after a particular project got under way, so that it could be examined at progressive stages. "I would like to avoid the problems we've seen in the construction prudency review," Badger says. "We want to do this up front and not get into these 10-year-later, hindsight, post-event reviews, which have caused a lot of problems in the industry." NARUC is expected to consider this change in policy at its upcoming July meeting in San Francisco. It would have to be accepted by the executive committee before it could be implemented.

NARUC is also working to develop formal principles on EA trading that utilities and their commissioners could use as a guideline. Naturally, it would be impossible for every state to handle trading the same way. According to Badger, the idea is to develop models for regions with common concerns.

One regulatory detail that tends to get dwarfed by concerns about allowance trading, power pools, and other big issues is that of efficiency incentives. The new legislation allows utilities to get extra EAs

The Trading Game

To encourage least-cost compliance, the revised Clean Air Act allows utilities to buy and sell the right to emit SO_2. For example, one utility's high-efficiency scrubbers may remove more SO_2 than the act mandates. For each extra ton of SO_2 removed, that utility will earn an emissions credit, which it may choose to bank for future use or to sell on the open market. Another utility, faced with higher SO_2 removal costs, may opt to purchase these credits if they are less expensive than the cost of reducing emissions. The dollar value of the emissions credits (also called emissions allowances, or EAs) is unknown at this time and will be determined by the market.



for programs that promote the use of more efficient end-use technologies. Some utilities already have such programs in place for the residential, commercial, and industrial sectors.

According to Phil Hanser, senior project manager in EPRI's Demand-Side Management Program, the legislation specifies that in order for utilities to use this method of gaining allowances, their commissions must have least-cost planning requirements in place, as well as some sort of regulatory mechanism to ensure that utilities don't lose money from their efficiency programs. While end-use efficiency will probably account for only a small fraction of all allowances, the long-term impact of this part of the legislation could be far-reaching, Hanser says. "Everywhere incentive mechanisms have been adopted, we've seen substantial, increased interest among utilities in demand-side management," he points out.

While there are no bonus allowances for efficiency on the supply side, utilities clearly can get more mileage out of their EAs by improving power plant heat rate.

The good news

Despite its challenges, the revised Clean Air Act does bring some good news for utilities. Because the regulations judge emissions compliance on a tons-per-year basis, utilities have much more flexibility in designing their flue gas desulfurization (FGD) systems (more commonly known as scrubbers) and NO_x control systems. This means ample opportunity for savings.

Historically, under the command-and-control approach to pollution legislation, utilities were in effect required to build redundant absorber capacity into their FGD systems at new plants as a safeguard against overemitting. Designs typically included multiple absorbers, one of which functioned as a spare. Redundancy was also built in through the provision of spare pumps and other equipment associated with each absorber. But industry studies have shown that the outage rate for absorber modules with good control of system chemistry is now typically less than 2%. So the need for spare modules is less compelling than in the early days of scrubber technology evolution. And with annual emissions limits, it is now permissible to bypass absorbers for short periods of time, as long as the total annual allowance is not exceeded.

FGD installations can account for up to 20% of the capital cost of a new plant. And the cost of a retrofit FGD system is usually considerably higher. EPRI's work has shown that design simplification, including the elimination of spare absorbers, is a critical area for savings in FGD retrofit systems. It is one key element of EPRI's SO_2 Advanced Retrofit (SOAR) concept, through which utilities can save 30% to 50% on the cost of an FGD system—equivalent to \$50–\$100/kW, or tens of millions of dollars.

Other elements of the SOAR concept include the use of chemical additives like dibasic acid, which can economically push the typical 90% SO_2 removal capability of scrubbers to as high as 99% in some cases. Additional cost-saving measures are simplified dewatering techniques and the use of a wet stack design with no reheat. With SOAR, FGD systems can maintain an overall reliability of more than 99%, consuming less than 2% of station energy input.

With improved FGD systems removing more and more SO_2, waste products will increase. EPRI is working to find uses for this material. Efforts are also under way to help utilities design environmentally compatible landfills for the waste in the event that potential markets for the product are not economical. EPRI program manager Michael Miller expects scrubbers installed for Clean Air Act compliance to produce a drier product than that of past scrubbers. This means it will have better potential as usable gypsum, which could become a source of revenue for utilities. Though markets for this by-product are small and localized, it is expected to be used in wallboard and cement and in highway construction. Utilities considering sale of their gypsum byproduct should begin looking for markets now, Miller says, so that any product specifications can be incorporated into the FGD system design.

In the area of NO_x control, ongoing EPRI research could result in technologies that save \$15–\$75/kW beyond the SO_2 control savings possible through SOAR. This would amount to \$5 million to \$25 million in capital costs at a typical 500-MW coal-fired plant. The EPRI projects are aimed at developing the next generation of low-NO_x burners, capable of achieving very low levels of emissions either without selective catalytic reduction (SCR) systems or with very small SCR systems. A postcombustion technology, SCR is considerably more expensive than combustion technologies but is capable of greater NO_x removal.

The lower level of savings (\$5 million) would be achieved through reduced-size SCR systems, perhaps small enough to be retrofitted without costly modifications to existing plant equipment. The upper level of savings (\$25 million) would be attainable if research succeeds in developing combustion technologies that combine controls for NO_x, SO_2, and particulates. One example would be a slagging combustor combined with a small, final cleanup device for catching residual pollutants the combustor misses. This technology combination would eliminate the need for a scrubber and an SCR system. Demonstrations and research are under way for both the slagging combustor and the accompanying cleanup device. Results are expected by 1997.

There are numerous areas for substantial savings in Clean Air Act compliance. EPRI encourages members to take advantage of its state-of-the-art information, the product of a decade of research into NO_x and SO_2 control, fuel markets, and utility planning methods. To help toward this end, the Institute has compiled a Clean Air Response Kit containing a number of relevant computer codes, reports, strategic decision methodologies, and market analyses, among other tools and information. Part of EPRI's Design and Retrofit Team (DART) initiative introduced in April 1990, the response kit is intended to be used by members and their technology suppliers, architect/engineers, and consultants. The package will evolve continuously, as new findings and tools emerge. (See the sidebar for highlights of this kit.)

EPRI's DART initiative also includes direct help to members in determining the least-cost compliance options for their plants. Services are designed to be short-term. Access to the Clean Air Response Kit and to broad strategic advice is free to all EPRI members. More specialized assistance from EPRI staff comes as a billable service.

Decisions still pending

Even as many utilities put the finishing touches on their strategic plans, there are a number of critical decisions still pending on Clean Air Act compliance. Deferred by the legislation to the EPA administrator, these issues include possible controls on air toxics emissions, as well as additional NO_x and SO_2 control requirements and alternative strategies. They have the potential for significant financial impact on the industry and could alter utilities' strategic plans.

In making his decisions, the EPA administrator will rely on the recommendations of his technical staff and on consultation with other federal agencies, including the Department of Energy and the National Park Service. For the more controversial issues, as well as those meriting further scientific information, the legislation directs the EPA to conduct studies before reaching regulatory decisions. EPRI is involved in research projects that will provide valuable input.

In the area of air toxics, for instance, EPRI has been working on a significant project for the past two years. Called PISCES (Power Plant Integrated Systems: Chemical Emissions Study), the project will result in a database and computer model to track potentially toxic chemicals in power plants. Users will be able to predict emissions for a variety of plant configurations, fuels, and environmental controls. They will also be able to assess the effectiveness of technological control options. Air toxics is only one component of the project, which also tracks chemicals in liquid and solid discharge streams. Currently, EPRI is measuring 24 potential air toxics at several representative power plants in the United States. These data, combined with existing information, will be used to conduct risk assessment studies. Supporting studies include research on the atmospheric chemistry of air toxics and on health effects (primarily of arsenic); health and ecological studies of mercury are also under way. (The sidebar on the Clean Air Response Kit provides more information on the PISCES code.)

Utilities currently are not regulated for air toxics at the federal level, and they are not the primary target of the amendments. But the legislation aims to reduce emissions of 189 substances considered air toxics by the EPA. About 37 of these have been identified as potential emissions from power plant stacks. The EPA and the National Institute of Environmental Health Sciences are conducting studies to help determine whether utilities should be regulated in this area. (For more information, see "New Focus on Air Toxics," *EPRI Journal*, March 1991.) EPRI has already been advising the EPA in order to ensure that the results of the Institute's research are incorporated in these studies. If the EPA deems them necessary, regulations could be imposed between 1995 and 1997.

A pending decision that may provide utilities with additional flexibility and savings in compliance involves trading SO_2 and NO_x allowances. With such a rule, if a utility's low-NO_x boiler reduces emissions significantly below the required limits, excess allowances could be

Clean Air Response Kit: Cutting the Cost of Compliance

EPRI has put together a Clean Air Response Kit of computer codes, decision methodologies, reports, and other information to help utilities develop least-cost strategies for complying with the 1990 Clean Air Act Amendments. Following are brief descriptions of some of the tools and information.

GETTING STARTED

Clean Air Response: A Guidebook to Strategies Often described as the nucleus of EPRI's Clean Air Response Kit, this comprehensive guide is designed to assist utility decision makers, engineers, and planners alike (GS-7150). It describes the strategic issues involved in developing a plan for Clean Air Act compliance and compiles findings from relevant EPRI research. It includes information on fuel markets, technology, emissions trading, and EPRI tools available to help with compliance.

COMPUTER CODES

FGDCOST This computer model estimates the costs of various flue gas desulfurization (FGD) processes. The user can enter site-specific information to get cost predictions for both new and retrofit applications. The first version, expected to be available this summer, will have a spreadsheet format. The user can select from 15 FGD processes, develop cost estimates for each, and compare the results. A later version, expected to be ready by fall, will feature the EPRIGEMS format and allow the user to select from 27 processes. The model can produce estimates of capital costs, operation and maintenance expenses, and total levelized costs. Estimates comparing FGD technologies are accurate to within 10% of actual costs. This code is a replacement for RETROFGD, an EPRI cost-estimating tool released in 1987.

FGDPRISM The FGD Process Integration and Simulation Model simulates wet lime and limestone scrubber chemistry and performance to help optimize the design and operation of existing FGD systems. It allows users to examine a number of process and equipment modifications without the need for expensive, time-consuming full-scale tests. It also can help in designing and evaluating new FGD systems. The program models the FGD system as a series of independent unit operations connected by process streams. Chemical reactions and the resulting performance can be simulated on a unit-specific basis. Unlike other process simulators, this code has extensive capabilities for handling ionic species. Released this year, the model features the EPRIGEMS interface.

NO_xPERT This code, currently in the final production phase of development, predicts NO_x emissions from a given boiler. It also will select potential combustion control technologies, given user input specifying the desired level of emissions reduction. In addition, the code will calculate the cost of NO_x emissions compliance, and it will indicate the impacts various control technologies could have on a boiler. This tool can be used to analyze an individual boiler or to analyze a group of boilers, for example, those in an entire utility system. The latter capability is particularly useful for averaging systemwide emissions to determine the best technical options for compliance. The code is expected to be released by late summer.

PISCES Chemical Assessment Model A product of the Power Plant Integrated Systems: Chemical Emissions Study, this code allows users to predict where specific chemicals will wind up as they move through a power plant. It analyzes the air, solid, and liquid streams. Users can specify any type of fuel and plant configuration. The model then tracks the flow of chemicals through the system and predicts emissions levels. PISCES can accept uncertainty in user input and report the probability of various outcomes. This makes it a particularly valuable tool for characterizing emissions of air toxics, since their concentrations are often not precisely known. Utilities will be beta-testing the program this spring, and EPRI plans to release a final version early in 1992.

CQIM The Coal Quality Impact Model estimates the total cost impacts of firing alternative coals in a specific power plant. Accounting for fuel costs, operation and maintenance costs, and replacement power costs, the model can quantify the pros and cons of coal switching, blending, and cleaning. It enables users to evaluate the option of low-sulfur compliance coals versus that of high-sulfur coals with scrubbers. A new feature is the model's ability to evaluate coal quality impacts on an entire plant, as well as on the individual units within a plant. Projected savings in fuel costs and in plant availability and maintenance costs run from tens of thousands to millions of dollars annually. Released late in 1990, this EPRIGEMS tool is the predecessor of a more sophisticated program in the works, an expert system called the Coal Quality Expert (CQE). A project of EPRI's subsidiary CQ Inc., ABB Combustion Engineering, and the Department of Energy, CQE is expected to be ready in 1994.

CAT Workstation The Clean Air Technology Workstation will be a platform for access to a number of other computer codes geared toward Clean Air Act compliance. Expected to be available by the end of the year, the code will provide the utility user with assistance in all phases of the decision-making process. Users can begin with screening studies of their systems, then move on to apply various cost, design, and performance tools for scrubbing, coal switching, and other options.

OTHER ACTIVITIES

Seminars This summer EPRI will sponsor a series of special instructional seminars on SO_2 control, NO_x control, and the impacts of coal switching, among other issues. Dates and locations will be announced.

Emissions Trading Simulation Workshop EPRI has established an emissions allowance trading "laboratory"—a workshop to help utilities get a better feel for the emissions allowance market. Each participant is given a utility, simulated on computer. The goal is to meet electricity demand at the lowest cost while complying with the Clean Air Act. To attain their goals, participants decide which plants to run and which are to use low-sulfur coal or scrubbers. They also may buy or sell emissions allowances or bulk power among themselves. The first simulation lab was held in Washington, D.C., in March. More sessions of the lab will be held in 1991 at locations still to be determined. A packet of pertinent information will be available to EPRI members, both attendees and nonattendees.

Many more tools are available to help utilities comply with the revised Clean Air Act. For more information, contact Ian Torrens, director of EPRI's Environmental Control Systems Department, at (415) 855-2422.

used to reduce the cost of SO_2 compliance. Likewise, excess SO_2 removal could reduce a utility's implementation of low-NO_x burners. EPRI information on the cost of NO_x and SO_2 control and on the environmental effects of NO_x and SO_2 emissions will provide critical information to an EPA study. Due to Congress by January 1994, the EPA's study will evaluate the environmental and economic consequences of NO_x–SO_2 trading.

With regard to NO_x control, few key decisions on the level of emissions limits were spelled out in the Clean Air Act Amendments. As the legislation stands, its provisions require the EPA to set NO_x emissions rate limits by early 1992 for Phase 1 units with tangentially fired boilers or dry-bottom, wall-fired boilers. By 1997 the administrator may revise these limits to be more stringent for Phase 2 units if it is determined that more effective low-NO_x burner technology is available. Also by 1997, the EPA is to establish rates for all remaining boiler types, including cyclone, cell, and wet-bottom boilers. NO_x limits for existing units are to be based on the capability of low-NO_x burner technology. But the mandated revision of the NO_x New Source Performance Standards (scheduled for promulgation by 1994), together with the existing EPA policy directing the use of top-down BACT (best available control technology) analyses for permit applications, opens up the possibility for NO_x limits too stringent for current low-NO_x burner technology to meet. Through comprehensive demonstrations, EPRI is exploring just what the capabilities of advanced low-NO_x technology may be and will share the results with the regulatory community.

Another critical issue is a study the legislation has ordered on the connection between NO_x and ozone. The study is to be presented to Congress next March. If it shows that reducing NO_x leads to an equivalent reduction in ambient ozone, local and state governments could require utilities (particularly those in or near urban areas) to reduce NO_x emissions further, which means that SCR could be required. EPRI has completed a study evaluating SCR costs and is now operating several SCR pilot plants, including the first in the world to run on high-sulfur coal. These experiments are expected to help determine the technological feasibility and cost of applying SCR to U.S. utility plants. Ongoing EPRI projects are also addressing the influence of NO_x in the formation of ozone. Since much of EPRI's atmospheric modeling work has been coordinated with EPA-funded studies, scientific communication with the agency already is established. This will help in communicating EPRI's findings.

With so many complex details still left to be ironed out, it's easy to lose sight of the big picture. Ask Jenkins of Tampa Electric, who regularly attends the ARAC meetings. "When we're in these meetings, the last thing that's ever brought up is the two words *acid rain*," he says. "Nobody even thinks about acid rain or fish or lakes or forests. We're into economics, regulatory procedures, SO_2 allowances, and so on."

For utilities, the big picture is not so much the issue of acid rain but how to respond. The law is the law, they say, and they must push ahead with compliance plans. "There's no point standing around saying 'it ain't fair,'" says Stevenson of Southern Company. "You just can't take that attitude now."

As Torrens points out, "Clean air response means that the industry must make some significant changes over the next decade. But the challenge is not insurmountable; utilities *can* reduce their emissions and deliver electricity cost-effectively. And EPRI-developed technologies and information are available to make the job easier." ■

This article was written by Leslie Lamarre. Background information was provided by Ian Torrens and George Offen, Generation and Storage Division, and Jeremy Platt and Jim Fortune, Integrated Energy Systems Division.

Ben

Dysart

From a variety of positions—on the Clemson University engineering faculty, as president of the National Wildlife Federation, and at the southeastern regional office of Chemical Waste Management—this environmental engineer and member of EPRI's Advisory Council has taught and sold ways to produce win-win trade-offs between conservation and development.

Making an Impact on Environmental Engineering

Ben Dysart remembers when he was four or five years old and was living on his grandparents' farm in middle Tennessee. "I spent a lot of time on a horse, riding double with my grandfather, bringing in the cattle, watching as crops were planted and harvested, seeing the interaction of land and people and weather and productivity—beginning to learn how things fit together.

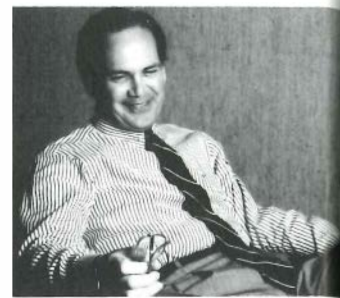
"You know, one of the things that may have gotten me started toward the conservation business was seeing my grandfather throwing rocks into gullies, putting tobacco stalks on bare areas to mulch the land, to keep it from eroding."

The memory remains one of Dysart's strongest. With the insight of an adult, he knows it influenced his later career decisions. "That's when I first got the notion of stewardship, of trying to care for the land, realizing that there was going to be not only a tomorrow but also a next year and a next generation—that how we use resources determines not only the quality of life today but how things will be in the future."

Other personal and historical events contribute to the combination of insight and hindsight by which Dysart gives meaning to his 51 years: a youngster's going hunting with his dad, a high school bass drummer's first trip to the West, a distaste for Latin, the launching of Sputnik, a dean's intriguing and timely redefinition of sanitary engineering, and the multifaceted concept of environmentalism that is now spreading through all of society and its institutions.

Out of all this has come a rich and varied career. Dysart became a professor of environmental engineering at Clemson University and taught there for 22 years; he has been a member, national director, and two-term president of the National Wildlife Federation during the last 16 years; and he is now facility development manager in the southern region of the United States for Chemical Waste Management, a major nationwide service for

"I got my PhD in civil and water resources engineering, and I've been having an absolute ball since then, dealing with the interfaces between science, engineering, technology, institutions and their purposes, people and their aspirations, society and its goals—all those things."



reducing, treating, and disposing of toxic wastes.

Dysart also is a member of EPRI's Advisory Council, joining 22 other men and women who review and comment on the Institute's research direction from their varied vantage points in U.S. occupations and interest areas—among them law, publishing, finance, utility regulation, education, government, and economics. Council members share a give and take with EPRI's management at three meetings and a two-day seminar each year, as well as in the continuing deliberations of ad hoc committees on specific issues. Foremost a means for EPRI to gain many public perceptions of electric power technology needs, the Council also fills an educational role by interpreting the Institute's research to its many constituencies.

Hunter, drummer, engineer

Dysart's years on the farm coincided with World War II. "I remember the day that President Roosevelt died and I was dispatched on horseback to tell my grandfather, my uncles, and all the hands that the president was dead." A year or two later his father returned from the navy to his pharmacy practice. The family was together again in Columbia, "in rolling bluegrass terrain—Tennessee walking horse country," says Dysart, "40-odd miles south of Nashville." He soon began to go hunting with his father, trailing along, as he puts it, carrying shotgun shells and picking up doves. "My father taught me the rules and a sportsman's approach to things. He also helped me understand how the critters and other wildlife—the nongame species—fit in with the land."

Growing up had a special meaning for Dysart, who is 6 feet 9 inches tall. "One of the first times I realized my height was when I was a head taller than my first-grade teacher." He passed 6 feet as a sixth grader and had added 3 more inches by the time he was in the eighth grade. "I stayed that way for a year, but in the tenth grade I grew another 5 inches." He recalls one problem along the way. "I was in the fourth grade, going out for Pee Wee League football, when the coach told me I couldn't play because they had a size limit—100 pounds—and I was already way over that."

Junior high school band offered Dysart an opportunity to turn the lemons into lemonade. "When you've got somebody my size with a strong back, you're going to strap either a sousaphone or a bass drum on 'em! I played bass drum." Even as a drummer, Dysart faced a special challenge. Acknowledging the pliers-like prosthesis on his left wrist, he says, "This is what happens when five-year-old kids don't have enough sense and get hung up in farm machinery." But the former drummer remains upbeat. "I think the good things have had a lot more to do with where I've gone in life than the lumps along the way. Other bass drummers use two hands; I just had to beat twice as hard and twice as fast with what I had!"

Playing in the band meant travel, and one of the good things during Dysart's high school years was his trip to a two-week band camp in the Colorado Rockies one summer. "That's when I first went trout fishing," he recalls eagerly. "I didn't catch anything, but I was fascinated by the cold stream, its gravel bottom, the vegetation, the trees. It was all so different from Baptist Branch, across the road from my grandfather's home, where I'd caught my first sun perch at the age of four. When I think about that first trip west, it's the stream I remember; it sure as heck isn't the fish I caught!"

When the time came to consider college, Vanderbilt, in nearby Nashville, was one obvious choice. Dysart had found high school Latin painful, and Vanderbilt required no further language study by engineering degree candidates, so half the decision was thereby made. What kind of engineering remained a question. This was 1957 and Sputnik had just been launched, so Dysart's father urged electrical engineering. "I spent a year and a half at it," says Dysart. "I didn't like it and it didn't like me. But I'd built lots of dams and tree houses and forts in my time, so I transferred to civil engineering and had fun all the rest of the way through."

Discovering environmental engineering

Dysart's first professional job became significant in ways that he hadn't expected. He went to work for Union Carbide in Tennessee and was assigned to plant engineering, with responsibility for any requirement that came up. "I learned all about Rube Goldberg engineering" is the way he puts it. "I learned how to do with what I had in the way of resources. I guess the biggest job I ever handled was

"Treatment plants are really there to protect the environment, not just to treat wastewater. We've got to go beyond the plant—upstream and downstream from it, in both the spatial and the temporal sense—to the institutions and actions that generate the waste and to those that are affected by the effluent."

only a quarter of a million dollars; but I'd go all the way from figuring the alternatives to arranging the funding, drawing it up, putting together the specs, bidding it, supervising construction, starting it up, and turning it over to the operating people." Thinking about his later years as a university professor, he adds gratefully, "All that gave me a perspective that too few faculty colleagues had—real-world experience with full accountability. It added a dimension to my teaching, and it was useful in gauging worthwhile research topics."

Union Carbide was Dysart's real world on two occasions. After a year there, he returned to Vanderbilt, where he earned a master's degree in sanitary engineering. "It wasn't really what I thought it would be," he remembers. "I thought I was going to save the environment, but we were just treating wastewater." His adviser urged him to go for a PhD in sanitary engineering, but the curriculum at that time—heavy on physical chemistry and microbial physiology—sounded to Dysart like "more and more about less and less," so he went back to Union Carbide to sort things out. Again, he gained significantly.

Tiring of the succession of urgent but unrelated plant engineering jobs, he began to ask what he could do that would give him more latitude, the opportunity to control his own schedule. "The answer I consistently got was academics. But I was also told I'd have to get my meal ticket punched—I'd need a PhD."

Happily, change was afoot in academia that was tailor-made for Dysart. Sanitary engineering was becoming environmental engineering, and, for that matter, engineering dealing with water resources of any type was beginning to embrace a universe of many more factors. In Dysart's words, "They were talking about engineering, economics, decision making, systems analysis, operations research, optimization, simulation, modeling, and so forth. It really got me going.

"I got my PhD in civil and water resources engineering at Georgia Tech, and I've been having an absolute ball since then, dealing with the interfaces between science, engineering, technology, institutions and their purposes, people and their aspirations, society and its goals, its frailties, its limitations—all those things."

During his final year of course work at Georgia Tech, Dysart sent letters and resumes to "all the great universities around the country and to a lot of not totally great institutions in the Southeast—about 60 in all." But at Christmastime, when his former Vanderbilt adviser expressed surprise that Dysart hadn't heard back from Clemson, Dysart admitted that for some reason he hadn't applied there. He immediately did so, and he still sounds incredulous today.

"I got a rapid response. Clemson's engineering dean was setting out to broaden both his sanitary engineering and water resources graduate programs. He realized that sludge busting and hydrology alone were no longer where it was at." As Dysart explains, the dean particularly wanted someone to "spiff up" the water resources program—to introduce some new management science approaches, such as operations research, mathematical modeling, simulation, and optimization.

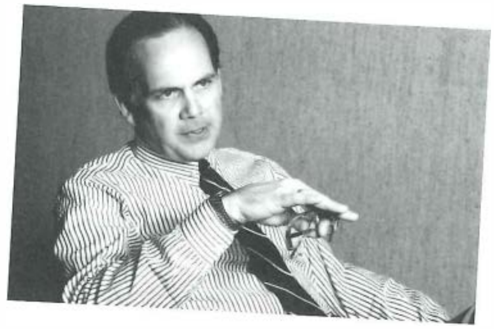
"What he wanted was exactly what I'd prepared myself for. I'd done my dissertation in discrete deterministic multidimensional dynamic programming. For about 15 minutes," Dysart adds with a twinkle, "I'd been on the leading edge of an important part of operations research!"

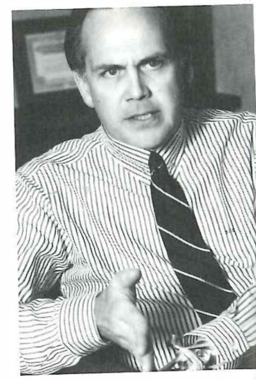
Needless to say, he joined the Clemson engineering faculty, and he stayed there for 22 years, working to update the two graduate engineering programs and eventually synthesizing them as the Environmental Management Systems Research Group. Dysart pauses and chuckles. "You know," he says, "when I started out, the thing that governed my first academic choice was whether I'd have to take a foreign language. It was a negative experience that tilted me into a slot, but before too long the positive started taking hold, and everything else was incremental change that got me out front in an evolving area, where I've been able to ride a good wave for a lot of years."

Environmental systems

When Dysart talks about environmental systems, he naturally starts at his professional cornerstone, sanitary engineering. "Treatment plants are really there to protect the environment," he says insistently, "not just to treat wastewater. There are linkages between the production or avoidance of waste, on the one hand, and the character and quantity of what you have to treat, on the other. We've got to go beyond the treatment plant—upstream

"When I was doing graduate work, anyone who could breathe could get research funded. Utilities could still do their generation planning with semilog paper and a straightedge. Now we're more concerned with cost-effectiveness, performance, delivery of benefits, accountability."





and downstream from it, in both the spatial and the temporal sense—to the institutions and actions that generate the waste and to those that are affected by the effluent."

Enlarging his field of thought, Dysart talks about the changes that have seemed important, even historic, during his professional years—"most of all," he says, "the onset of concern about environmental quality, environmentalism. You know, there are people who think we're just off on a big tangent these last 10 or 20 years, that things will come on back to normal. My philosophy is that things have fundamentally *changed*—in society, in the economy."

Dysart's account suggests that tightening budgets have been a pervasive catalyst of change. "When I was doing graduate work, you could sell absolutely anything you could produce. It was a time when utilities could still do their generation planning with semilog paper and a straightedge. And in the universities anyone who could breathe could get research funded. We could throw money at problems, and we did. But a few years later, things began to tighten up. Now we're more concerned with cost-effectiveness, performance, delivery of benefits, accountability. We don't want any surprises. It's been a 180-degree turn for people in resource development and management."

Clearly, Dysart is again in the classroom as he recaptures the message he developed for a generation of graduate students at Clemson: "If our business is simply designing waste treatment plants, there's not a whole lot to play around with. But if we're trying to protect the environment—an off-site river, a wildlife habitat, a fish habitat, or a cold water stream—then we're equally interested in doing things smart enough to where we don't generate the waste to begin with."

Dysart adds that it generally is cheaper to avoid waste than to separate and treat it after it's been mobilized. "I don't have a commitment to designing treatment plants," he says. "I'm trying to protect the environment to the extent that society wants it protected—that is, taking into account society's ability to pay and the trade-offs with other social investments."

And Dysart believes society is more insistent on protecting the environment these days, especially when it can see and evaluate those trade-offs. He falls into dialogue with himself, first hypothesizing a treatment plant with a price tag of $40 million, then responding with a litany of other societal needs, such as health care, housing, defense, and a renovated transportation infrastructure. "Somebody is going to ask if we really must spend the $40 million that way," Dysart goes on, "and the answer may well be that we can get the same results for $4.5 million through a combination of education, a low-tech approach, and figuring out ways not to produce so much waste in the first place."

If his thesis sounds simplistic, Dysart is the first to admit that it finds resistance, even—or perhaps especially—in some of the technology community. "Soft stuff doesn't generate the big bucks in fees that hard stuff does," he comments wryly, "and besides, people get nervous when you challenge conventional wisdom."

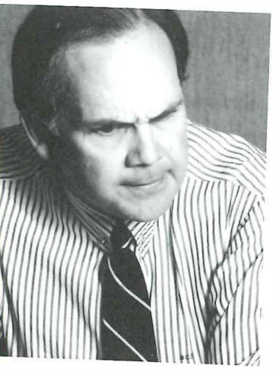
Hazardous-waste management

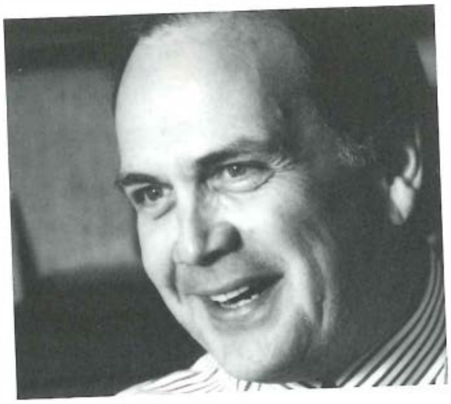
As Dysart talks, the question arises as to whether he counts himself a teacher or a salesman. He acknowledges both. "I enjoyed teaching. I enjoy selling ideas. In order to attract top-notch students, you must convince them that you have something they can't get elsewhere. You also have to sell new research proposals to the funding sources."

English was Dysart's best subject in high school, and he claims to have been the only freshman engineering student at Vanderbilt who got an A in English in 1957. It shows. "I've always enjoyed the creative expression of ideas, packaging and presenting ideas so they appeal to people, rally them, motivate them. You know, we're all selling. Unless you can package science and technology effectively—orally, in writing, in photographs, in some way—you're not going to get support. Nothing will happen."

One begins to sense that Dysart has always positioned himself where he can have the most environmental impact with his particular set of talents. Asked why he left Clemson in June of 1990, he recalls how he answered the question for himself even earlier. "I decided that if I found someplace where I could have more fun and impact, I'd be there very shortly. That's what I find at Chem Waste. It's a big game. It's a big challenge. It's an opportunity to put a big spin on some important decisions."

Chemical Waste Management is one of





"I've always enjoyed the creative expression of ideas, packaging and presenting ideas so they appeal to people, rally them, motivate them. Unless you can package science and technology effectively, you're not going to get support. Nothing will happen."

three operating companies of Waste Management, Inc. The largest operates nationwide, providing engineered disposal sites and transportation for all manner of conventional domestic and commercial solid waste. Another company provides services in 16 other countries. And Chem Waste handles hazardous materials only—anything that must not go into a municipal landfill. Chem Waste has its own subsidiary to deal with low-level nuclear wastes.

Dysart's work brings him together with many corporations and their managers, as well as with all levels of federal, state, and local government agencies and jurisdictions. "There's an evolving need for treatment, storage, and disposal facilities in the South, and they need to be sited, permitted, and put into operation. Our clients aren't just big corporations but also haulers and brokers who pick up smaller quantities here and there. It's that simple."

The need is pressing, and it's also sensitive. "You've got this NIMBY thing—'not in my back yard'—to contend with. And it also doesn't help that some cheapo haulers dump toxics off the road somewhere, or that shortsighted companies transport hazardous materials to Third World countries for a price." Chem Waste is one of the few companies competing to upgrade and lead the industry by strict environmental and procedural compliance and by their own R&D. "We want things done in an absolutely first-rate manner. Our customers don't want to worry about anything coming back on them; they want it done right. We want them, and the regulatory agencies, to insist on high performance. That's good for us. As standards get tougher, we think we have a real competitive advantage."

Dysart is in a fast-moving business, and he is restless himself, easily admitting he doesn't like to get bogged down in details that cloud the overall objective: "I certainly don't like slow-moving operations that smart people recognize are going nowhere. I like to be out in front." And along with that preference, he has a positive bias, an expectation that most problems can be worked out. "Either that," he says, "or I get to where I realize something won't work and it's time to find an alternative that can be a winner."

Conservationist or environmentalist

In keeping with his positive bias, Dysart calls himself a conservationist rather than an environmentalist. He's concerned that the latter term is so often pejorative—"you know, shrill voices calling for a stop to everything." He goes on, "To me, conservation connotes realism, recognition that problems need responsible attention but that the world still has to go on—that we need places to work, electricity, highways, trees cut to make two-by-fours. There have to be trade-offs." In his view, conservationists participate in the public process. As long as it can work and as long as they can be a part of it, they stay at the table and try to move things constructively.

Another member of EPRI's Advisory Council, Victoria Tschinkel, has suggested that improved environmental behavior is, more than anything else, a matter of grass-roots education and awareness. Dysart agrees, citing the pervasive problem of non-point-source pollution as proof. "If there's a pipe coming from a factory, you have an obvious place to stick a treatment plant. Diffuse-source pollution is tough to pin down and tougher to regulate. You're talking about developers, builders, agriculture, and just plain individual people. You don't have a tail to twist."

The example of agriculture becomes graphic as Dysart evokes the image of varied pesticides, herbicides, nutrients, and fertilizers, plus the problem of education, which can so quickly be seen as interference. "But we're not talking about just agriculture. Think of the things that get spilled on the road, what gets washed out of our yards. A lot of our surface water and groundwater problems are traceable to diffuse pollution sources."

An advocate of cost-effectiveness, Dysart sees a strategic problem for utilities and other industries that have a stake in environmental cleanup. Cost-effectiveness doesn't flow from a single formula, he points out; it isn't handbook engineering. "It calls for latitude, for institutional adjustments. Let's have some swapping, some trading, not just a single technology fix for everyone.

"If utilities want to avoid having measures crammed down their throats that aren't cost-effective, they must get public opinion on their side. That's the strategic problem. I think the acid rain debate is one where the private sector lost the initiative, if they ever had it."

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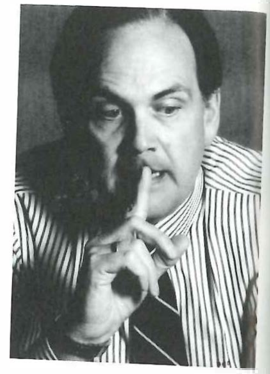


Dysart regrets what he calls a simplistic SO_2 solution that nailed everybody. As he sees it, some utilities have already done a great deal, and they feel stuck. Others, perhaps causing more of the problem, are being treated like everyone else. "It saddens me," he says, "in a time when financial resources are tight. I hate to see money wasted, even in a good cause."

The comments are evidence of Dysart's familiarity with electric power industry waste problems. Indeed, during his long tenure at Clemson, he consulted with many utilities, among them Duke Power and the Tennessee Valley Authority. With his long suit in waste management and his long participation in environmental conservation affairs with the National Wildlife Federation, Dysart was a logical choice (in 1989) for service on EPRI's Advisory Council. And he has thoroughly enjoyed it. "EPRI has a genuine desire to get our input—the up side, the down side, what we think, and why. There's no desire to have any punches pulled."

Asked for an example, he returns to acid rain and the issue of SO_2 controls. "We've considered the role of EPRI's research results. Were they credibly reported? Were they sort of after the fact? For me, the feeling was that this deal had already been done, that science and technology didn't have much influence on how things went with the new Clean Air Act legislation."

But such questions remain relevant to EPRI's research on electromagnetic fields and their public health implications. For these and other topics, Dysart and his Council colleagues believe there's time to ask what has been learned from the acid rain debate and, among other things, to shape research inquiries differently—to answer the questions that are most meaningful to the public and its decision makers. "How can we put wheels on EPRI's research," asks Dysart, "bigger and better wheels? I think EPRI is properly concerned that it not be seen as an advocacy organization, that it be seen as an honest broker—and also that its work be more widely and usefully applied."

Dysart himself is unequivocal. "EPRI needs to be more proactive. It must get its research results into a form that public policy influentials can understand—legislators, congressional staff, bureaucrats, regulators, and so on. People aren't going to beat down doors to ask for science briefings. But they need to know how it is, the pros and cons of alternatives that are on the table—as well as what alternatives are missing."

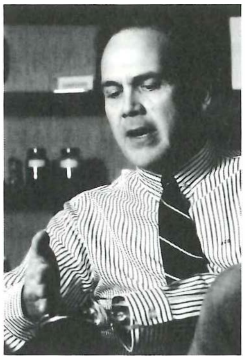
The quality of EPRI's work seems to be a given underlying the Council's deliberations. Dysart agrees, saying he considers it a terrific bargain for the utility industry. "When I see what is going on now, and the changes and challenges that are likely on the planning horizon—why, there are a number of topics on the research plate that will affect the industry's health and profitability. I can't see any compelling argument why utilities shouldn't be supporting EPRI at a higher level than they are."

Finding pulpits for his mission

Beyond teaching and selling, there's a bit of preaching in Ben Dysart. It isn't heavy; it's good-natured. It comes out in his conviction that systems must be as inclusive as possible—of engineering, economic, environmental, and societal considerations. He feels a sense of mission in his life and career: "I think it's to find the blend of good science and engineering that can be mixed with sensitivity and appreciation for soft values—environmental stewardship and responsibility—so that we can keep the world moving along and maintain viable economies, too, and so that people in the future can look back and say, 'They did a pretty good job.'"

Over the years Dysart has tested his views and his capabilities in a number of guest pulpits, so to speak. One important occasion was his going to Washington as science adviser to the assistant secretary of the army for civil works in 1975. It was a year-long, full-time appointment, from which he particularly remembers having encouraged changes in the Corps of Engineers design for upgrading the Atchafalaya floodway, which protects New Orleans on the lower Mississippi River.

A conventional trapezoidal diversion channel was being proposed to carry more than a million cubic feet of water per second through several hundred thousand acres of first-order wetlands that Dysart calls some of the finest hardwood overflow ecosystem in the country. "The solution wasn't to stop something," he says, "but to be more creative, to work smarter." Cleverly designed weirs now retard flows being diverted into the floodway, allowing silt- and nutrient-laden waters into the overbank areas but keeping sand loads in the main channel,



"I think we've been sitting on the back of the wagon—our strategy and planning and engineering still based on a view of the past. What I've tried to do in my teaching, my research, and my mentoring of some very able young people is to prepare them to sit on the front of the wagon."

which continues to sluice them seaward.

Later on, Dysart served two terms on the Environmental Protection Agency's Science Advisory Board, where he further developed his skill as a facilitator or translator by "working in the seam," as he puts it, between people with quite different viewpoints and approaches, not to mention awesome responsibilities, budget problems, and deadlines nobody could meet. "In the seam," he clarifies, "that's kind of where the corn is as it's being ground up in the grist mill."

The National Wildlife Federation has to be Dysart's first love and is the pulpit he held the longest, from 1974 to 1990. When talking about environmental education, he can't resist a plug: "I like to think that NWF has helped educate millions of young Americans through Ranger Rick's Nature Club and its monthly magazine." Drawn to NWF as a sportsman, Dysart worked with it at the state level and then served as a national director for 16 years, including two terms as national president and board chairman.

He singles out no one NWF cause or project from those years. Instead, perhaps predictably, he emphasizes NWF's continuing promotion of rational resource management and environmental protection. As elsewhere, he was a catalyst or facilitator, he says, "helping diverse players with different ideas find common ground and work toward worthwhile goals." Dysart is convinced that the U.S. conservation community is much more sophisticated and effective today than it was 15 or 20 years ago. "We're using good science and good engineering and good economics to supplement our good instincts—our love of what Aldo Leopold, a real philosopher of conservation, used to call things natural."

Upon leaving the NWF presidency in 1985, Dysart volunteered with both the Conservation Foundation and the René Dubos Center for Human Environments. As a senior fellow at the foundation, he worked for a year and a half on a national wetlands policy project sponsored by EPA.

His Dubos Center affiliation was, in effect, invitational: he was elected a trustee. "I was fascinated by the organization," Dysart says. "Supported mostly by corporate contributions, it was founded in 1969 by Dr. Dubos, who had a very positive philosophy, very much a matter of 'think globally, act locally.' He had the notion that if people are smart enough to create problems, then they also are smart enough to figure out good ways to solve them. He also believed that the world is probably a whole lot better off because mankind is here, and that change isn't always bad. That's a pretty positive philosophy, you know, and it attracted me."

Dysart's early activity included chairing a panel on water resources at the center's annual forum in 1985. These forums are issue-based occasions, he explains, where as many as 120 individuals, from many backgrounds and constituencies, are invited to deliberate for two or three days, hearing background papers, learning where they agree and disagree, but seeking consensus—"trying to figure out how to move from square one to square two, how we can create a win-win situation." Almost needless to say, Dysart remains close to the Dubos Center; he was elected vice chairman in 1990.

Asked if there has ever been anyone that he'd like to trade places with, Dysart deflects the question by saying, "I'd like to have collaborated with Aldo Leopold. He did so much in developing the conservation ethic, the land ethic, the notion of wise and responsible resource management in this country. I think it would be nice to have been a coauthor or a footnote in all that."

The thought prompts Dysart to sum up how he has tried to influence the practice of environmental engineering. "I have a metaphor. I think we've been sitting on the back of the wagon, looking at where we've been. So much of our strategy and planning and engineering are still based on a view of the past."

He describes how we polluted rivers and streams and then solved the problem with treatment plants. Meanwhile, we invented synthetic chemicals and then had to pass more laws to get the chemicals out of the wastewater too. But we didn't say where to put them, so we created the still greater problem of hazardous wastes and what we now call Superfund sites.

"In the next 15 or 20 years," Dysart concludes, "I'd like to see us get smart enough not to create even worse problems. What I've tried to do in my teaching, in my research, and in my mentoring of some very able young people is to prepare them to sit on the front of the wagon." ■

This article was written by Ralph Whitaker, science writer, from an interview with Benjamin Dysart.

TECH TRANSFER NEWS

EMF and Risk Communication

Possible health risks from exposure to electric and magnetic fields (EMF) have recently received widespread attention in the popular press. As a result, customer questions to electric utilities about transmission facilities and other sources of EMF have increased considerably. Two reports are now available from EPRI to help utility spokespeople communicate with customers about these issues.

Risk communication is a difficult task, at best. All audiences perceive information through their own attitudes and beliefs. In speaking to an audience about health risks, technical experts may feel they are presenting irrefutable facts; those in the audience, however, will be listening for something completely different: whether the expert is empathetic to their concerns. If this empathy is missing, the facts don't get across. Communication about possible risks from EMF is especially problematic because there is still much scientific uncertainty in this area.

According to project manager Gordon Hester, there is a divergence between how engineers manage risks and how the public perceives those risks. Researchers have found that risk incidence is only one of several factors that the public responds to. For example, automobile drivers are at far greater risk of accidental injury than people who live near nuclear power plants, but the latter group is often far more concerned. "There are clear patterns in public responses to various risk elements," says Hester. "Public response depends to a great degree on such factors as how familiar the risk is, how dreaded its effects are, and whether effects are reversible." Communication efforts are more effective when these factors are taken into account.

The new EPRI publications apply insights from the field of risk communication to the problem of communicating with utility customers about EMF health effects. "When utilities begin to get calls on EMF," says Hester, "they get much better results if they are prepared." The purpose of the *Handbook for Communicating Potential EMF Risks* (EN-7046) is to show how to put together a coherent program involving teams from across the company. "It's a procedural guide that walks utility managers through the analysis of objectives, audiences, and credible communicators and the evaluation of effectiveness—all focused specifically on the health effects of EMF," says Hester.

Objectives are defined in terms of the needs of different audiences. Consideration is given to developing risk messages in the face of scientific uncertainties and to selecting communicators whose credibility is appropriate for each audience. Examples of appropriate EMF messages and credible communicators are given, and the question of earning trust is addressed. Finally, a strategy for evaluating the success or need for adjustment of the communication effort is outlined.

As a companion piece to the handbook, the *Risk Communication Manual for Electric Utilities* (EN-7314) provides guidance for the individual communicators who will actually convey the risk messages to the public. The manual presents principles and methods that can be used for a variety of risk topics, audiences, and situations, including media interviews, public meetings, and emergency response.

Links between risk communication theory and practice are illustrated by seven case studies. The topics covered include nuclear waste management, air pollutants, and hazardous waste, as well as EMF. Detailed analyses of the case studies illuminate why risk communication succeeded or failed in each instance and bring home the key communication dos and don'ts outlined in the report.

Together, the EMF handbook and the risk communication manual provide a clearly defined, proactive approach for listening and responding to community concerns on possible EMF risks. ■ *EPRI Contact: Gordon Hester, (415) 855-2696*

Fossil Plant Life Optimization

EPRI has just published *Life Optimization for Fossil Fuel Power Plants* (GS-7064), which provides updated guidelines for plant evaluation and component assessment, a description of research results and case studies, and a guide to the supporting tools available from EPRI and elsewhere. The report augments condition assessments of 25 critical and major plant subsystems compiled and published earlier in *Condition Assessment Guidelines for Fossil Fuel Power Plant Components* (GS-6724). According to EPRI project manager Barry Dooley, "These two reports help utilities to approach the life assessment process in a logical fashion—and *not* to do the most complicated and expensive things first."

From an initial emphasis on assessing and extending component life, the project documented in these two reports grew into a more comprehensive approach. As early component assessments went forward, the need to make decisions about component reliability called for higher-level decisions on maintenance, reinspection, and replacement. According to Bob Wykoff, who has helped apply this research to 12 plants owned by Centerior Energy in Ohio, the result has been a "proactive tool for expense and capital planning over the life of a unit." The set of methods and the overall approach developed in the project thus respond to the requirement that utilities maintain operating capacities in the most economic and environmentally responsible way.

The life optimization volume emphasizes the need for upper management involvement and introduces the multilevel approach to data gathering. As Dooley explains, "The idea is that initially data gathering is to be kept simple, mainly limited to calculation procedures." Where more information is required, a second level of effort is called for—detailed inspection procedures. Finally, for critical components that are difficult to replace, sampling procedures may be specified.

Centerior's Wykoff emphasizes the report's value. It shows, he says, that "the key is to organize life assessment objectives logically. Utility planners should look at unit operational history first, gathering component knowledge from plant and outside sources." Then, at the next scheduled outage, a logical series of inspections of critical components can be performed. Finally, after reviewing the results of these first two levels, utility personnel may decide that a detailed engineering analysis is needed for some parts of a unit. "The basic benefit of this program," says Wykoff, "is to provide the information and tools to assist in making the right decisions about these units and how they fit into the company's resource planning process." ■ *EPRI Contacts: Barry Dooley, (415) 855-2458, and Stephen Gehl, (415) 855-2770*

Commercial-Grade Items for Nuclear Plants

As technology changes and the number of suppliers of nuclear-grade replacement parts shrinks, utilities are faced with the issue of procuring commercial-grade items and qualifying them for safety-related applications. To assist in this endeavor, EPRI is coordinating the activities of the Joint Utility Task Group (JUTG), a working group of about 40 utilities, in developing technical evaluations of commercially available replacement parts for the nuclear industry. Results from the group's evaluations are available to member utilities through EPRINET, the Institute's on-line information and communication network.

Commercially available parts are acceptable as nuclear replacement parts if they have been "dedicated," or qualified within regulatory guidelines, for use in nuclear facilities. In the late 1980s, studies carried out jointly by EPRI and NCIG (a utility group cosponsored by the Institute) established a generic process for dedicating safety-related items for nuclear applications.

This process and associated methodologies are documented in EPRI report NP-5652, *Guideline for the Utilization of Commercial-Grade Items in Nuclear Safety-Related Applications (NCIG-07)*. The dedication process identifies an item's technical design attributes and basis, selects acceptance criteria for the item, and recommends inspection and test criteria to ensure that an item will perform its intended safety-related function.

Application of the NCIG-07 approach revealed the need for additional detail for performing the technical evaluation portion of the dedication process. Work to provide this detail was completed in December 1989 and is documented in NP-6406, *Guidelines for the Technical Evaluation of Replacement Items in Nuclear Power Plants (NCIG-11)*.

As well as ensuring acceptable replacement part availability, application of the NCIG-07 and -11 guidelines can provide financial dividends. For example, Niagara Mohawk procurement engineers applied the new process when they received a bid for 100,000 feet of qualified wire quoted at five times its off-the-shelf price. Two utility staff members did a vendor survey to procure the wire as a commercial-grade item and saved the utility $395,000 in the process.

The JUTG was established to further broaden the use and effectiveness of the commercial-grade item approach, specifically by gathering information on previous dedication actions, reducing duplication in conducting item and vendor evaluations, and avoiding variations in implementation. The group has coordinated technical evaluations of dozens of replacement part candidates, using the processes established in the joint NCIG–EPRI studies. As part of its work, the JUTG has produced the Commercial-Grade Items Database, which contains current information about suppliers and the latest data on replacement parts. Technical evaluations and acceptance criteria for 28 items have already been entered in the database. The listing of suppliers gives identity, location, quality assurance approaches, and relevant survey data.

Since the responsibility for procurement specifications, item dedication, and supplier selection must remain with the utility, use of the data available on EPRINET cannot in itself guarantee that a nuclear operator will meet procurement guidelines. However, as Tom Mulford, who coordinates the JUTG efforts for EPRI, points out, "the work has been completed by a group of technical personnel responsible for performing this activity in their own plants. Since they know the benefits of its future use, there's a quality going into it that might not be possible except through the synergy of such a group. I think they've done a good job in capturing important information in these technical evaluations and putting it into the database."

Further information is available from EPRI about what the database contains and how to access it through EPRINET. ■ *EPRI Contact: Warren Bilanin, (415) 855-2784*

Gasification Power Plants

Highly Efficient Advanced Cycles

by Neville Holt, Generation and Storage Division

Increasing the thermal efficiency of coal-fired power generation reduces both the amount of fuel required and the amount of waste products created, including carbon dioxide and ash. Coal gasification–based systems make it possible to use high-efficiency gas turbines and fuel cells in cycles offering marked improvements over steam-based (Rankine) cycles. Furthermore, because these systems remove the emission-forming constituents of coal before the power generation process, they represent an option for meeting very stringent environmental standards. Over the next decade, a succession of gasification-based systems will be commercially introduced. This update presents the results of recent EPRI research in this area.

ABSTRACT *Recent EPRI work and developments in Europe have led to substantial improvements in coal gasification, gas cleanup, and gas turbine technology. As a result, gasification–combined-cycle plants based on current gas turbines can be designed with heat rates approaching 8000 Btu/kWh (42.7% efficiency). Moreover, the integration of currently available gasification processes with molten carbonate fuel cells promises to offer heat rates of about 6500 Btu/kWh (52.5% efficiency). These efficiencies represent a considerable improvement over conventional coal-fired units, and the cost of electricity is competitive. Although the initial capital cost for such advanced systems is still greater than that for conventional coal plants designed to U.S. New Source Performance Standards, promising cost reduction concepts are being explored.*

Site-specific GCC studies

During 1987–1989, EPRI, in cooperation with member utilities, conducted several site-specific coal gasification–combined-cycle (GCC) studies. The results of these studies are presented in reports GS-6161 (Northeast Utilities), GS-6176 (Florida Power & Light), GS-6283 (Baltimore Gas & Electric), GS-6493 (Virginia Power), and GS-6876 (Southern Company Services).

A variety of coal gasification technologies were studied. The designs for nominal 400-MWe GCC plants using the General Electric 7001F gas turbine (2300°F turbine inlet temperature) generally had heat rates of 8950 Btu/kWh, ±175 Btu (higher heating value, or HHV, basis). When this information was used in the utilities' generation expansion planning models, it was found that the GCC plants were usually dispatched up to their equivalent availability (typically 85%).

On the basis of the low U.S. coal costs and EPRI's Technical Assessment Guide economic assumptions regarding capital charges and taxes, the GCC studies showed a trade-off of about $120/kW in capital cost for a heat rate improvement of 1000 Btu/kWh. Current concerns regarding the potential greenhouse effect and discussions of a proposed carbon tax constitute additional motives for EPRI's increased attention to efficiency improvements. Any future legislation aimed at addressing these issues may well result in increased incentives for such improvements.

The site-specific GCC studies were all based on the gasification and gas turbine technology current in 1987 and on the integration concept (steam only) pioneered at the Texaco-based GCC demonstration plant at Cool Water in 1984–1988. Since the studies were conducted, EPRI has cofunded several important projects that will result in considerable improvements to the already attractive efficiencies and costs cited above.

European GCC developments

European coal costs are higher than coal costs in the United States. Also, the capitalization and taxation philosophy in Europe provides a greater incentive for capital investment for efficiency improvements than is provided under current U.S. rules. Consistent with this philosophy, European companies have developed more highly integrated GCC designs that promise heat rates of about 8000 Btu/kWh (HHV basis) with 2300°F gas turbines.

A prominent feature of many such designs is to take the air for the air separation unit (ASU) as a bleed from the gas turbine air compressor. Gaseous oxygen from the ASU is fed to the gasifier, and gaseous nitrogen from the ASU is compressed and sent to the gas turbine to provide additional motive force and to reduce thermal NO_x (Figure 1). This arrangement eliminates the need for a separate air compressor for the ASU.

With cofunding from Florida Power & Light and Virginia Power, EPRI is conducting a study (RP2221-20) to compare a GCC plant designed in this manner with the more conventional (steam-only) integration used in the earlier EPRI studies. The design work is being carried out by a team from Krupp-Koppers, Siemens–Kraftwerk Union (KWU), and Linde; Sargent & Lundy is providing translation to the U.S. situation. This study has so far confirmed that with a 2300°F gas turbine, the air extraction scheme can achieve a heat rate of about 8000 Btu/kWh, which represents an advantage of about 200 Btu/kWh over the conventionally integrated scheme. A capital cost comparison is expected to be completed later this year.

Cooling-water temperatures are frequently lower in European plants than in many U.S. plants, and as a result, lower stack temperatures and higher-efficiency steam cycles (lower vacuum) can be achieved. Since sulfur compounds in the GCC fuel gas can be reduced to very low levels at small incremental costs beyond the costs of meeting U.S. New Source Performance Standards for coal-fired power plants, low stack temperatures can be used without fear of acid dew point corrosion at the cold end.

In EPRI's earlier U.S. studies, it was already recognized that heat recovered as a result of using lower stack temperatures could be applied to the saturation of the fuel gas. However, the use of low-level heat recovered in this way was limited by the fuel gas minimum heating value—190 Btu/scf (HHV basis)—set by General Electric at that time for its 7001F gas turbine. (Recent work cofunded by EPRI, Shell, and GE has since relieved this limitation.) In contrast, the European gas turbines from Siemens-KWU and ABB Asea Brown Boveri have large, refractory-lined silo combustors that can accept fuel gases down to 100 Btu/scf. With such gas turbine combustors, more low-level heat can be used to saturate the fuel gas. In addition, nitrogen from the ASU can be added to the fuel gas before saturation so that even more hot water can be evaporated, providing yet more motive flow to the gas turbine.

In May 1989 the consortium of Dutch utilities, SEP (NV Samenwerkende Elektriciteits-Produktiebedrijven), announced plans to construct a 250-MWe GCC plant at Buggenum, Netherlands. This plant will use a single Shell gasifier train of 2000-t/d capacity linked to a single Siemens-KWU V94.2 gas turbine combined cycle (2000°F turbine inlet temperature). Stringent environmental standards, including zero water discharge from the gasification facilities, are required. The high-efficiency integration features of the recent European GCC designs described above are included in the SEP design. The design heat rate is 8240 Btu/kWh (HHV basis), or 41.4% efficiency. Construction has begun, and a mid-1993 startup is planned.

RWE (Rheinisch-Westfälisches Elektrizitätswerk), the largest electric utility in Germany, has also announced a GCC project. The feedstock is to be Rhenish brown coal, and the gasification technology is to be the High-Temperature Winkler fluid bed. An 800-t/d (10-bar pressure) HTW unit has been operating successfully in Germany since 1986, producing gas for methanol synthesis. Also, a 150-t/d (25-bar pressure) HTW pilot plant is being operated by Rheinbraun, a RWE subsidiary. (Under RP2656-3, EPRI is currently funding work with Rheinbraun to explore the application of this process to U.S. bituminous coals.) The gas turbine for the GCC project is to be a Siemens-KWU V94.3, which will have a turbine inlet temperature of about 2300°F and will de-

Figure 1 In the highly integrated GCC designs favored in Europe, air for the air separation unit (ASU) is taken as a bleed from the gas turbine compressor, and nitrogen from the ASU is returned to the fuel gas for saturation and combustion. These designs promise an efficiency of 42–45%, compared with about 40% for the conventionally integrated design.

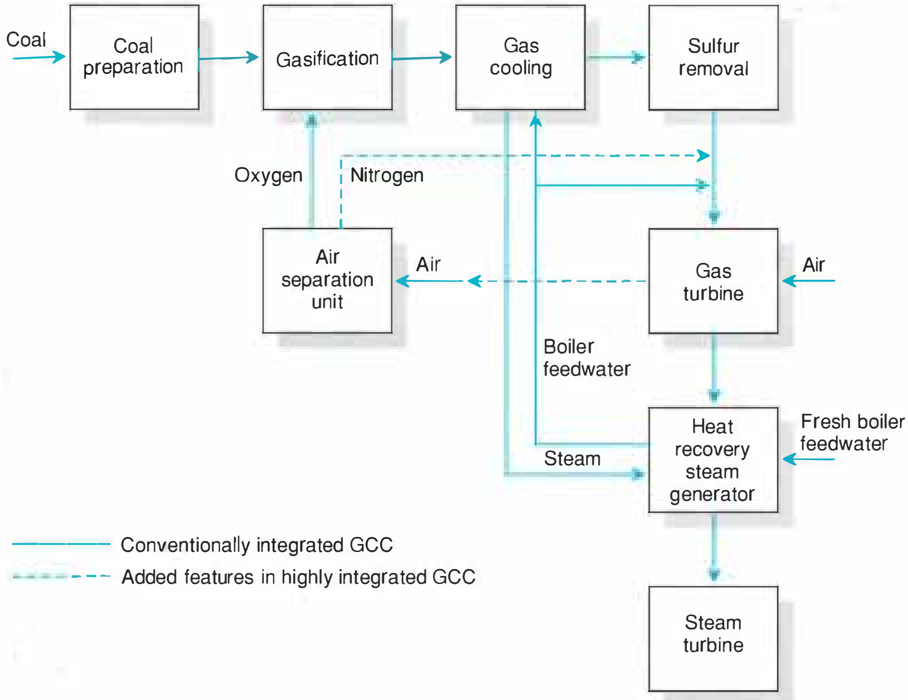
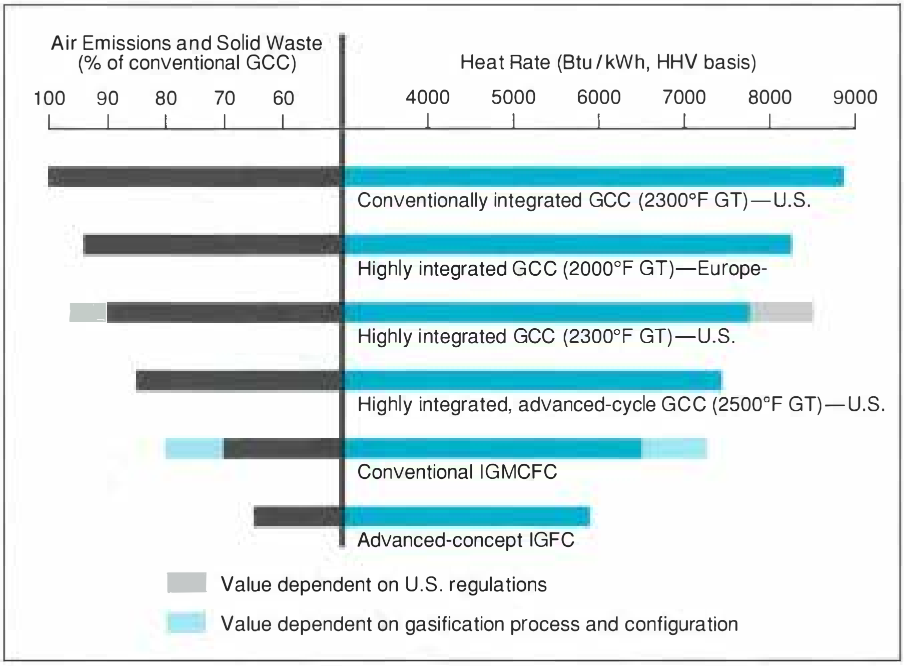


Figure 2 Over the next decade, a progression of increasingly clean and efficient coal gasification–based power plants will be developed. This series of advances will provide utilities with environmentally benign coal-based generation options for the twenty-first century. (GCC = gasification–combined cycle; GT = gas turbine; IGMCFC = integrated gasification–molten carbonate fuel cell; IGFC = integrated gasification–fuel cell.)



liver about 200 MWe. An efficiency of over 44% is forecast for the 300-MW plant, scheduled for startup in 1995.

Gasification process improvements

In 1987 test programs began at SCGP-1—the large (250–400-t/d) Shell gasification pilot plant in Deer Park, Texas, which is cofunded by EPRI under RP2695—and at the 160-MW Dow (2400-t/d) unit in Plaquemine, Louisiana. Since that time, many improvements have been successfully demonstrated.

At SCGP-1, Shell has been able to increase throughput and reduce the amount of transport gas used to feed the coal. This has increased the cold gas efficiency from the earlier 78% to 82–83%. (Cold gas efficiency is a measure of how much of the fuel coal's chemical energy appears as chemical energy in the fuel gas.) The higher cold gas efficiency means that more of the coal's energy can be provided as fuel to the more efficient Brayton (i.e., gas turbine) cycle than as sensible heat to the less efficient Rankine (i.e., steam) cycle.

The use of hot particulate removal devices (ceramic candle filters) has also been demonstrated at SCGP-1 at temperatures of about 450°F. These devices simplify downstream gas and water cleanup requirements, and if they prove effective at higher temperatures (like those planned for pressurized fluidized-bed combustion units), they will offer even further efficiency and cost improvements.

Gas turbine improvements

The performance projections for the GE 7001F gas turbine combined cycles used in EPRI's early site-specific studies were formulated before GE had the benefit of any actual operating experience. The first such unit entered commercial service at Virginia Power's Chesterfield station in June 1990. On the basis of experience with this unit, GE can guarantee improvements in both power output and efficiency over the initial estimates. Moreover, EPRI (under RP2620), GE, and Shell have cofunded work at GE to focus on GCC applications of the turbine, originally primarily designed with natural gas as the intended fuel. The work's objective was to plan modifications and operational changes to the design that would take full advantage of the synergistic opportunities stemming from the higher mass flow and combustion characteristics of coal-derived gases in a GCC context.

Thermodynamic and mechanical analysis, along with experience with the turbine at the Virginia Power plant, has shown that output can be increased to 192 MWe at standard temperature and pressure conditions (compared with an output of about 150 MWe used in EPRI's earlier GCC studies), and that a 240-Btu/kWh heat rate improvement over earlier estimates can be achieved.

Combustion tests have been carried out on a full-size 7001F combustor can at full temperature and pressure (RP2620). The fuel gas composition was equivalent to that of gas from an oxygen-blown Shell gasifier with steam dilution. The tests showed stable combustion (low CO) and low NO_x emissions with fuel gases down to 130 Btu/scf. As previously stated, GE had set a heating value limit of 190 Btu/scf in the earlier GCC studies. These recent tests have shown that GCC plants based on the 7001F turbine can use low-level heat to saturate the fuel gas and thereby improve efficiency. Furthermore, it is now possible to use the 7001F in the high-efficiency, highly integrated manner planned for the European units described earlier.

Future improvements

Developments in aircraft turbine technology are expected to push turbine inlet temperatures over 2500°F by the turn of the century, which should lead to further improvements in utility gas turbines. EPRI has initiated study on several advanced gas turbine cycles, such as the humid-air turbine (HAT), the intercooled steam-injected gas turbine, and the chemically recuperated gas turbine. The HAT cycle is a particularly promising concept in terms of capital cost reduction.

Beyond the gas turbine advanced cycles, EPRI has also conducted several studies on the integration of coal gasification with molten carbonate fuel cells (MCFCs). The impending demonstration of a 2-MW MCFC has lent further impetus to this work.

In a recent study of integrated gasification-MCFC systems (RP2930-1), a higher-pressure version of the near-commercial British Gas–Lurgi gasifier was used with a slightly modified fuel cell configuration, including anode gas (hydrogen) recycle. The BGL process was selected for several reasons involving synergism with the MCFC. It has a high cold gas efficiency (85–88%), which means that more of the coal's energy is converted to fuel gas for use in the more efficient fuel cell and less is converted to sensible heat in a less efficient steam bottoming cycle. The BGL process also uses less oxygen than entrained gasification processes use, which further improves efficiency. The fuel gas from this process contains about 30% of its total heating value as methane, which is the ideal fuel for MCFCs.

The study found that the integrated gasification-MCFC plants, nominally 500 MWe, had very low coal-to-busbar heat rates—about 6500 Btu/kWh, or 52.5% efficiency. Unfortunately, the capital cost was estimated to be about $2000/kW. Several opportunities for cost reduction have been identified, and the plant designs will be modified for further investigation.

The highly efficient power-generating devices under intensive development, such as higher-temperature gas turbine–based cycles and MCFCs, all require a clean fuel. In addition to the environmental advantages of low emissions, the clean gas from coal gasification will enable the use of these devices in a progression of high-efficiency coal-fired power plants (Figure 2). Such plants will ensure that the electric utility industry maintains its coal-based generation capability in an environmentally benign way.

Nuclear Plant Corrosion Control

On-line Prediction of Crack Growth in BWR Piping

by Raj Pathania, Nuclear Power Division

Intergranular stress corrosion cracking (IGSCC) of stainless steel piping has been a major cause of unavailability in boiling water reactors. The factors contributing to IGSCC are high residual stresses produced by weld shrinkage; susceptible material conditions (i.e., a sensitized microstructure) in the heat-affected zone of the weld; and an aggressive environment.

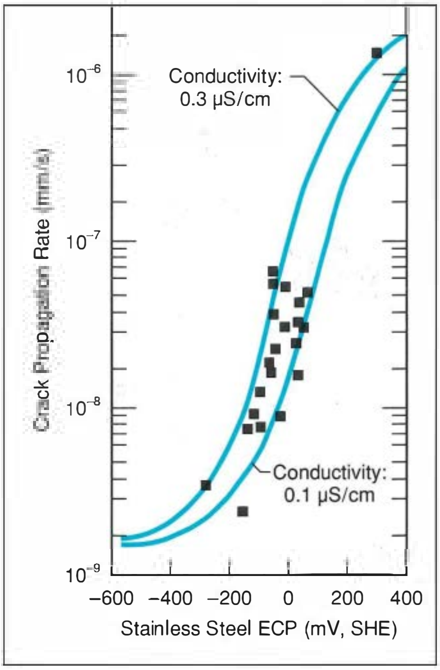
Remedial methods of controlling IGSCC have been developed in cooperative efforts by EPRI, the BWR Owners Group, and vendors. These include resistant materials, thermal and mechanical processes to minimize residual stresses, weld overlay reinforcements, improved water chemistry, and hydrogen injection.

BWR utilities have implemented many of these remedies in the field, and as a result, the incidence of IGSCC in BWR piping has decreased considerably in recent years. The Nuclear Regulatory Commission has issued a generic letter (88-01) recognizing the effectiveness of the remedies and specifying inspection schedules that depend on the remedial methods used.

When indications of IGSCC are found by inspection, it is necessary to evaluate the rate at which the cracks could grow during subsequent operation so that sound decisions can be made regarding continued operation versus piping repair. The crack propagation rate depends on stress, the microstructure of the pipe material, and water chemistry. To evaluate crack growth, a predictive model must correlate the propagation rate to these parameters. Such a model has been developed by General Electric under RP2006-6 and will serve as a key component of an on-line, personal computer–based system for predicting IGSCC growth in BWR piping.

ABSTRACT *A newly developed model can predict the growth of intergranular stress corrosion cracks in stainless steel piping in boiling water reactors. The model is part of an on-line life prediction system that is being developed to allow real-time monitoring of crack growth in BWR piping by using personal computers. Such a system should enable utilities to perform quick assessments of fracture margins under plant operating conditions and assist them in planning in-service inspections. One utility used the predictive model to assess the impact of a water chemistry transient and avoided a costly midcycle outage.*

Figure 1 Effects of electrochemical corrosion potential (ECP) and ionic conductivity on the crack propagation rate in Type 304 stainless steel exposed to BWR water at 288°C. (ECP is evaluated against the standard hydrogen electrode, or SHE.) There is good agreement between model predictions, shown for two conductivities (curves), and experimental data (symbols).



IGSCC predictive model

The new model postulates that strain at the tip of a crack causes rupture of the protective oxide film that forms on the stainless steel during operation. The fresh metal surface exposed corrodes rapidly in the crack tip environment. This environment is more aggressive than the solution outside the crack because of the buildup of corrosive species within the crack. As the crack tip continues to corrode, the crack advances. Meanwhile fresh oxide is formed, slowing down the rate of corrosion and crack growth. Continued strain ruptures the oxide film again, and crack growth is sustained by recurring cycles of oxide rupture, crack tip corrosion, and oxide formation. The walls of the crack, which are covered by the protective oxide, do not corrode significantly.

The researchers developed a quantitative model that relates crack growth rate to ionic and oxidizing impurities in water, applied and residual stresses, and metallurgical variables. The model postulates that the strain at the crack tip is the driving force for IGSCC. The crack growth rate increases with increasing stress intensity factor, an engineering parameter that is related to strain rate at the crack tip. The crack growth rate also increases with increasing ionic conductivity, which results from such water impurities as sulfate and chloride. These impurities may enter the BWR water through condenser leaks or through the ingress of ion-exchange resins. Another factor affecting crack growth is the presence of oxidizing species (e.g., oxygen and hydrogen peroxide) in the water. One measure of the water's oxidizing power is the electrochemical corrosion potential (ECP) of the stainless steel.

The predictive model relates crack propagation rate to both ionic conductivity and ECP. This is illustrated in Figure 1, which presents model predictions for two conductivities together with experimental data. It shows that to decrease the crack propagation rate, it is necessary to reduce the ECP and/or the conductivity. By providing such information, the model can help utilities quantify the benefits of improved water chemistry control.

A comparison of crack growth predictions with experimental observations from a large number of tests has indicated that the model is accurate to within a factor of 2 or 3 when material, stress, and environmental parameters are accurately defined. The uncertainty in prediction is considerably greater when these parameters are not well defined.

In an early application, Carolina Power & Light (CP&L) used the model to assess the impact of a water chemistry transient in a BWR. The plant experienced a resin intrusion that increased the coolant conductivity well above the limits specified in the BWR Owners Group water chemistry guidelines. Needing a nonintrusive method of evaluating the transient's effect on the plant piping, the station staff applied the IGSCC predictive model, in consultation with EPRI. The assessment concluded that the transient would have a negligible effect on the extension of any preexisting cracks. This conclusion was confirmed by data from in-plant crack growth sensors. CP&L staff decided that a midcycle outage to inspect the piping was not warranted. In this instance, CP&L avoided $1.75 million in outage costs by applying the predictive model; savings over the next 25 years are estimated at $11.4 million.

On-line life prediction system

An on-line system to predict IGSCC growth in BWR piping is a logical extension of the predictive model. Such a system is being devel-

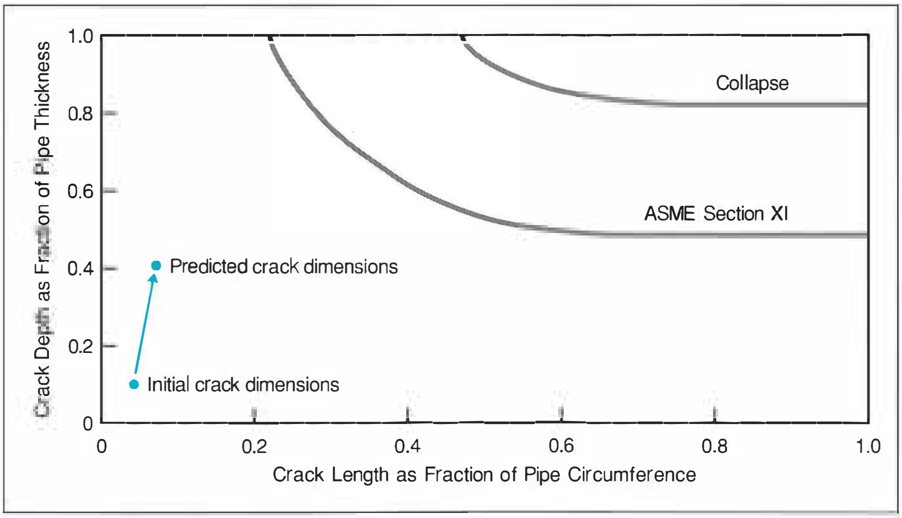


Figure 2 This flaw acceptance diagram produced by the on-line prediction system shows the calculated growth of a hypothetical crack over a specified time period (color). To illustrate the available margin, the diagram presents the ASME Section XI code criteria that indicate when piping must be repaired or replaced, as well as crack dimensions that define piping collapse.

oped by General Electric for EPRI under RP2006-17. The system consists of software that runs on a personal computer and allows real-time monitoring of crack growth in piping as a function of plant water chemistry. The software has four modules. A water chemistry module and a plant data module each feed output to a crack growth module, which in turns feeds a fracture mechanics module.

The water chemistry module accepts input on conductivity and ECP from a plant's water chemistry data acquisition system. ECP measurements are made with silver–silver chloride or copper–copper oxide reference electrodes. The module also allows users to input conductivity and ECP values; for accurate predictions, however, it is important to use data from in-plant sensors.

The plant data module contains plant-specific information on welds, pipe size, and applied stresses. On the basis of these data and data from the water chemistry module, the crack growth module uses the IGSCC predictive model to calculate the crack growth rate. Finally, the fracture mechanics module determines cumulative crack depth and length as a function of time for a preexisting crack. This module contains information on the residual stress distribution in pipes of various sizes. It can evaluate both axial and circumferential cracks. Figure 2 presents typical output in the form of a flaw acceptance diagram. It shows the predicted growth of a hypothetical crack for specified operating conditions and provides an assessment of available margin based on ASME code criteria.

The on-line system has been verified against laboratory data. These data were obtained from tests on precracked 4-inch- and 10-inch-diameter pipes instrumented with sensors for the precise measurement of crack growth. Later this year, a host plant will be selected for demonstration of the system.

The on-line prediction system described here provides rapid assessment of crack growth and fracture margin under actual plant conditions. It can be used to assess the impact of water chemistry excursions on crack growth. The system should be a particularly useful tool in optimizing plans for in-service inspections.

Integrated Value-Based Planning

Becoming a Customer-Focused Utility

by Phil Hanser, Customer Systems Division

Over the last two decades, the electric utility industry has changed dramatically. Before the 1970s brought oil shocks, inflation, and the Three Mile Island accident, the utility industry was characterized by rapid and steady growth, declining generation costs, relatively short construction lead times, limited competition, and a relatively sympathetic regulatory climate. Today's industry, in contrast, is characterized by relatively low and uncertain growth, rising generation costs, long construction lead times, rapidly increasing competition on both the supply side and the demand side of the meter, and greater regulatory and political scrutiny. These changes require that utilities modify, often dramatically, the manner in which they do business.

In the past, success depended largely on how well a utility managed its construction program, fuel procurement, operations, and rate case procedures. Customers were often taken for granted—or, at the very least, poorly understood.

Construction, operations management, and rate proceedings are still extremely important. But today being successful requires doing many more things well. Given rising capacity and generation costs, success often means avoiding construction through effective demand-side programs. Given that regulators are increasingly tying profits to performance incentives, success often means convincing customers that using less electricity does not mean getting less value. Given rising retail rates, success often means improving service and implementing cost reductions at the same time, thereby convincing industrial customers not to bypass the system and residential customers not to pressure regulators for rate reductions.

ABSTRACT *To be more successful in the increasingly complex and dynamic markets in which they operate, utilities are seeking ways to improve their customer focus. Being customer-focused requires doing two things well: listening to customers and cost-effectively delivering the goods and services they want. In its project on integrated value-based planning, EPRI is developing concepts and tools to help utilities assess and improve their commitment to customers.*

The common element underlying all these critical success factors is the customer. As declared in a *Business Week* cover story (March 12, 1990), in today's dynamic market the customer is king, and "at companies that listen hard and respond fast, bottom lines thrive." Utilities recognize the crucial importance of their customers, but after decades of addressing primarily supply-side issues, many of them are unclear about what it means to be customer-focused. As evidence of their commitment to customers, utilities often point to state-of-the-art market research departments, multimillion-dollar demand-side management (DSM) programs, and quality management programs. But although these can all play important roles in implementing customer-focused strategies, they do not in and of themselves define a customer-oriented utility.

Market research, while quite useful, is not the only means of understanding customer needs; moreover, understanding those needs and meeting them are clearly two different things. Properly motivated and designed DSM programs can be an important part of a customer-focused strategy, but many utilities approach DSM planning as a resource planning process, not as an opportunity to give customers what they want and are willing to pay for. And quality management techniques can reduce costs, improve productivity, and stimulate innovation; if companies are not listening to their customers, however, such techniques may simply be helping them improve their ability to deliver products and services that customers don't want.

What it means to be customer-focused

To help utilities become more customer-focused, EPRI is developing concepts and tools they can use to assess and improve their commitment to their customers. The Institute's integrated value-based planning project (RP2982-4) emphasizes customer-focused planning (CFP), which is defined as a process that makes the customer the focal point of all utility planning and activity and uses customer value as the driving force of business strategy.

Key words in this definition highlight several important concepts. The first—highlighted by the word *process*—is that, in spite of its name, CFP is more about doing than about planning. Customer needs are constantly changing, and to be successful, utilities must establish organizational procedures and processes that anticipate and respond to rapidly moving targets.

The second concept, highlighted by the use of the word *all*, is that for this approach to be truly effective, the idea of being customer-focused must permeate an entire organization—not just the marketing department, where its value is often best understood.

The third, and perhaps most important, concept is that of *value*. The primary objective of CFP is to create value for customers through the continuous improvement of existing products and services and the development of new products and services that meet customer needs.

At the most fundamental level, being a customer-focused utility requires doing just two things well: listening to what customers want and delivering. Obviously, these essential activities are more easily said than done. In fact, utilities throughout the industry are in quite different stages of development in these two areas.

In terms of listening, most utilities are typically in one of three stages:

- Inattentive: Customer opinions are neither being sought nor being heard; for whatever reason, the utility is distracted.
- Attentive: Customer needs are perceived as important, and customer information is being accumulated.
- Seeking: The utility and its customers work hand in hand to improve understanding and create value for customers and shareholders alike.

In terms of the ability to deliver, utilities are also typically in one of three stages of development:

- Ineffective: The utility may be listening, but its current levels of skills and resources prevent it from effectively meeting customer needs.
- Reactive: The utility responds to competitive threats and opportunities but succeeds primarily in holding its ground.
- Proactive: The utility is a leader in product and service quality and innovation, and it works closely with consumers and regulators to create and deliver value.

Figure 1 shows the stages of listening and delivering in a matrix format. The proactive, seeking utilities are clearly the industry leaders, while the inattentive, ineffective ones lag behind. At the other two extremes are the inattentive but proactive utilities and those that actively work with customers to understand their needs but can't deliver. The former are oblivious—they are very good at what they do, but they are doing the wrong thing. The latter are obviously frustrated. In the middle are the followers, utilities that listen but respond only in a reactive manner and, at best, succeed in holding their ground relative to the competition. EPRI's integrated value-based planning project is designed to help utilities become leaders in their commitment to customers.

Listening

Market research is clearly one way to improve corporate understanding of customer needs. Accordingly, it has dramatically proliferated in the utility industry over the last two decades. Driven initially by the need to improve long-range forecasting and to identify trends in the penetration of demand-side technologies, utilities began to conduct frequent and large-scale customer surveys in the mid-1970s. These focused primarily on the characteristics of building and equipment stock.

By the mid-1980s, in part because of disappointment with the levels of DSM program participation, utilities had come to realize that buildings and equipment don't determine electricity use—people do. Utility market research began to focus on the factors that affect purchase and utilization decisions and on the sometimes complex processes involved in making those decisions. Guided by such research as EPRI's customer preference and behavior project (RP2671), utilities have implemented numerous market research studies to identify and, in some cases, quantify general customer needs.

Market research has continued to evolve in

Figure 1 Customer-focused planning requires listening to customers and delivering the products and services they want. Utilities vary in terms of how well they perform these activities, but most fall into one of three developmental stages for each, as shown in this matrix. EPRI is developing tools to help utilities improve their listening and delivering skills, which are critical to success in today's business environment.

Delivering \ Listening	Inattentive	Attentive	Seeking
Ineffective	Lagging		Frustrated
Reactive		Following	
Proactive	Oblivious		Leading

the utility industry. Quite recently, some utilities have begun to focus on understanding customer needs in much greater detail, on understanding the relationship between customer needs and satisfaction, and on tracking customer perceptions of utility performance. Utilities are beginning to realize that it is not enough to know that customers value reliability quite highly, for example, or even how much they value reliability relative to, say, price. To develop programs, utilities would have to understand precisely what customers mean by reliability—to understand, for example, the relative importance to customers of outage frequency and duration.

Utilities would also have to understand how customer perceptions of reliability are formed. Are they based primarily on how fast utilities respond during an emergency outage? Or are they based on how often the customer comes home to find 12:00 flashing on an electronic clock? (Some customers think power quality is reliability.) If utilities don't develop an understanding at this level of detail, they will risk offering new and innovative products and services that customers don't want, will expend valuable resources on activities that matter very little, or will become lulled into complacency by high overall customer satisfaction ratings without knowing why they're high—and, more important, how they might change in the future.

An important characteristic of a truly customer-focused utility is the recognition that even the most sophisticated market research will not always reveal what customers want in terms of new or improved products and services. This is because customers don't always know these things themselves, especially in an industry where, historically, choices have been limited by regulatory constraints and lack of competition.

Sometimes the only way to determine whether customers want something is to let them try it. For example, if asked in a survey 15 years ago what features they would like in their telephone service, few respondents could have described the numerous alternatives currently on the market. Customer preferences for alternative product attributes were revealed—not only to the telephone company but to the customers themselves—when the company introduced new options and gave customers choices. Although this trial-and-error method can be difficult and costly in a regulated environment that rarely rewards risk and innovation, it is often the only way to identify alternatives that may fail in theory but be wildly successful in practice.

Still another way of listening to customers is to involve them more directly in the planning process. Some utilities maintain ongoing consumer panels that can be used not only to track changing attitudes and preferences but also to obtain input on new plans and strategies. Other utilities involve customers through "partnering," in which representatives from a utility work one-on-one with large, key customers to attack a specific problem, such as power quality. Collaborative procedures, such as those currently being used in a number of jurisdictions to develop incentive mechanisms for fostering DSM, are another forum whereby utilities and customers can work together to develop mutually beneficial plans. The key to successful collaboration, however, is having consumer representatives that truly represent consumer interests, and this is not always the case. Whatever method is used, involving customers directly in the planning process can be an efficient and effective means of listening to them.

Delivering

Understanding customer needs is one thing; meeting them is quite another. In recent years, utilities have implemented a wide variety of management and organizational changes in an attempt to improve their ability to provide quality products and services at reasonable cost. Time-based competition, cycle time reduction, supplier integration, flexible manufacturing systems, cost control, work force planning, total quality management—these are among the concepts being preached, practiced, and sometimes discarded in an attempt to cope and, ideally, thrive in a rapidly changing industry. Layered on top of these changes are frequent and significant reorganizations designed to decentralize, recentralize, or otherwise reorient the functional activities of a utility and, quite often, to move responsibility and accountability closer to the customer.

Any of these techniques or strategies, and many others as well, can be quite useful in improving a utility's ability to deliver what customers want at a profitable price. One of the most important tenets of CFP is that there is no single approach to becoming customer focused, no magic formula. An approach that succeeds at one utility may fail miserably at another. Success or failure will depend on corporate culture, the skills and capabilities of the work force, the regulatory environment, and myriad other factors. The key to success is matching the technique and approach to the specific characteristics of the organization.

This does not mean, however, that there aren't a number of specific actions that a utility must take in order to deliver effectively. In fact, there are at least three that should be mentioned. Regardless of what else a utility does to improve its customer focus, it will more than likely fail if these three things are not part of the process:

- Defining goals and objectives in concrete terms
- Relating each activity within the utility directly to the customer
- Measuring performance in terms that matter to customers

Perhaps the biggest single obstacle to becoming customer-focused is the fact that customer focus, though its value is undisputed, is not very meaningful in the abstract. To be responsive to its customers, a utility must take the concept of customer focus from the abstract to the concrete.

For example, regardless of taste in food, most people recognize McDonald's as a company that knows what customers want and that is good at delivering. When asked how it does this, McDonald's will reply that it delivers quality, service, cleanliness, and economy. No one can argue with these objectives, but they are not per se what makes McDonald's a customer-focused company. What makes it customer-focused is that it can also say that quality means a $1\frac{5}{8}$-ounce hamburger cooked to medium; service means the customer waits in line no more than 90 seconds; cleanliness means customers are within 50 feet of a restroom that has been cleaned within the hour; and economy means a child can eat for under $2.

Similarly, a customer-focused utility does not define its objectives simply as high reliability, low cost, and friendly service but goes on to define these attributes in concrete terms. High reliability might be defined, for example, as "VCR clocks will not flash 12:00 more than once a week," low cost as "the residential customer will pay less than 8¢ per kilowatthour," and friendly service as "a customer service representative will address the customer by name at least twice in each call." Regardless of what else a utility does, if it does not define its objectives in concrete terms, it will never know whether it's winning or losing and, if the latter, how to fix the problem.

The second thing a utility must do to be customer-focused is to relate each of its activities to product and service attributes that matter to customers. This is called attribute/activity mapping. If each employee does not understand what his or her actions contribute to customer satisfaction, those actions could easily run counter to what is in the best interest of the customer and, therefore, the utility.

For example, ask a utility financial officer what it means to be customer-focused and you are likely to receive a reasonable answer. However, if you then ask whether he or she is customer-focused, the reply may well be, "Oh, that's not my job; I'm in finance." Consider other possibilities: "That's not my job; I'm in personnel" or ". . . I'm in the warehouse" or ". . . I'm in tree trimming."

The fact is that each of these individuals has a direct and significant impact on attributes that matter to customers. Customers want low cost, and the decisions of the finance department have a very important impact on the cost of electricity. Customers want friendly service, and the decisions of the personnel department have a direct and important impact on who is hired as a customer service representative. Customers value high reliability; the frequency of outages is affected by the decisions of tree trimmers, and the duration of outages is affected by the decisions of the warehouse personnel who manage spare parts inventories.

The point is, everybody's job is linked in some way to creating the product and service attributes that affect customer satisfaction. The problem is, workers and managers often don't understand these linkages. It is critical to make the links between attributes and activities explicit. Figure 2 presents a partial, prototypical attribute/activity map for electricity supply reliability. By developing and using similar maps for the other important product and service attributes that matter to customers, and by understanding the relative contribution of each activity to the customer's perception of performance, managers and

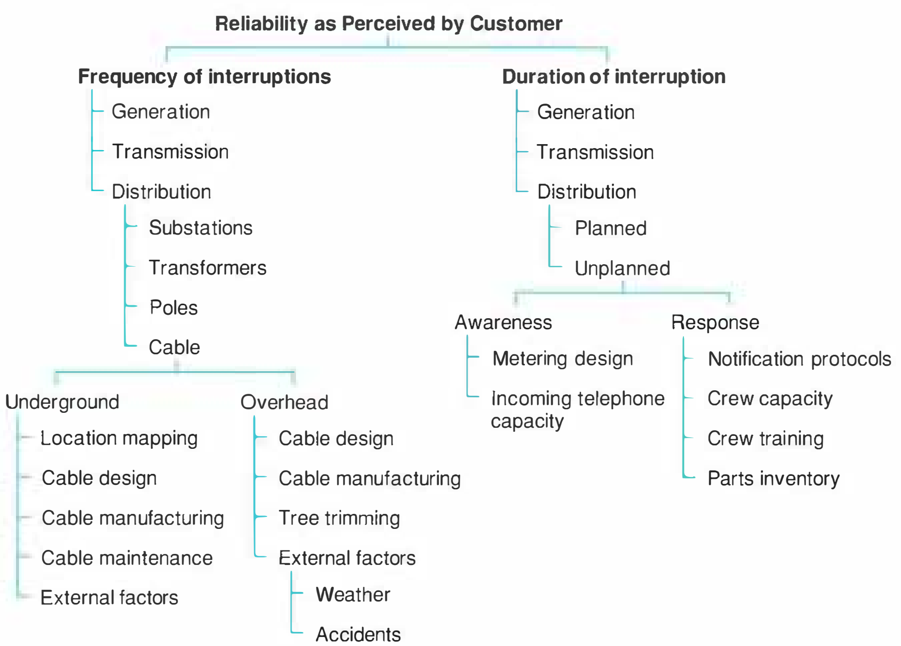


Figure 2 Attribute/activity maps show the links between utility activities and the product and service attributes—in this prototype, electricity supply reliability—that matter to customers. By clarifying these links and showing how various jobs contribute to customer satisfaction, the maps are a useful tool for improving utility performance.

workers alike will be able to make informed judgments about resource allocations and ways to improve customer service.

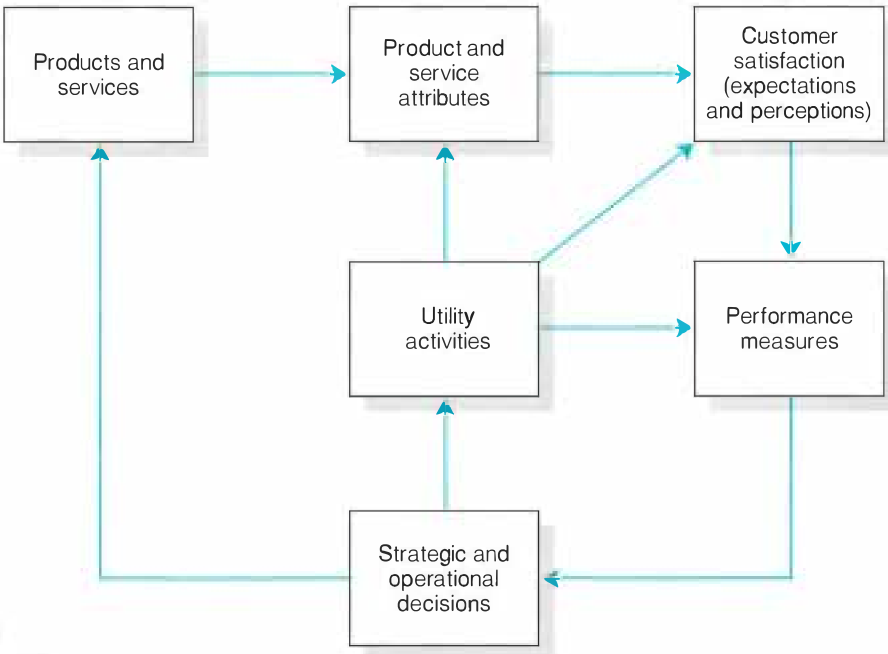
The third critical element in developing a customer focus is performance measurement. Two well-known rules in management are "You get what you ask for" and "You can't manage it if you can't measure it." Put another way, these adages mean that you get what you measure and that if you measure the wrong thing, you'll get the wrong thing. Customer-focused utilities measure what matters to customers and, over time, improve performance and customer satisfaction.

For example, if a utility understands the importance of "prompt and courteous service" but measures the performance of customer service representatives only in terms of the average number of calls answered per day, it will not get prompt and courteous service. To get prompt and courteous service, a utility must first define in concrete terms what this means to the customer—answering each call within three rings, referring to the customer by name, and, if the inquiry is not resolved on the telephone, replying with additional information within three working days—and then measure performance on these actions only.

Figure 3 depicts a customer-focused performance measurement system, which begins by defining each product or service offering in terms of attributes that shape customer perceptions (e.g., price, reliability, quality, safety). These attributes are defined in concrete, measurable terms through focused market research and trial and error. The primary indicator of customer satisfaction is the difference between what customers perceive and what they expect. Utility activities determine product/service attributes and thus customer satisfaction. (Attribute/activity maps are used to clarify these relationships.) Also, as indicated by the direct arrow from activities to customer satisfaction, certain utility activities (e.g., advertising) may operate directly on customer perceptions and even on expectations. Performance measures track customer expectations, customer perceptions, and utility activities.

Such a system provides valuable input into strategic and operational decisions, as well as the day-to-day decisions and actions of each worker. Ultimately, it will lead to changes in activities, improved products and services, and the development of new product and service offerings.

Figure 3 A customer-focused utility assesses its activities in terms of how well they meet customer expectations. It tracks customer satisfaction. (Most utility activities influence customer satisfaction by influencing product and service attributes; some, such as advertising, shape customer perceptions directly.) A performance measurement system like the one shown here informs strategic and operational decisions and leads to improvements and innovations in product and service offerings.



EPRI products

Customer-focused utilities, then, must do two things well—listen and deliver. To listen well, utilities must focus market research on customer expectations and perceptions, recognize and act on the fact that customers don't always know what they want until they've experienced it, and incorporate customers more directly into the planning process. To deliver well, utilities must define goals and objectives in concrete terms, relate each activity within the utility directly to the customer, and measure performance in terms that matter to customers.

Through its integrated value-based planning project, EPRI is developing concepts and tools to help utilities improve their customer focus. The project is applying these tools in several case studies and chronicling the historical experience of utilities that have implemented customer-focused strategies. Among the specific products and reports being developed are the following:

- An overview document describing in detail the fundamental concepts of CFP.
- A diagnostic instrument that can be administered within a utility to assess, in part, how well the utility is listening to its customers and how well it is able to deliver. This instrument can also be used in group settings to facilitate dialogue and identify solutions to key problems. It is being applied in two case studies (at Commonwealth Edison and PSI Energy), which will be documented in detail. It has already been administered in a workshop to representatives of over 50 utilities.
- A detailed case study (at Commonwealth Edison) describing the development of a customer-focused performance measurement system, including the construction of attribute/activity maps.
- A series of short case descriptions of the

development of innovative product and service offerings at selected utilities.

▫ A summary and critique of market research on understanding customer expectations and perceptions about utility product and service offerings.

▫ An annotated bibliography of pertinent literature.

Future work will address, among other things, the value of end-use services and will examine mechanisms for incorporating this value into the design of customer programs.

Commercial Program

Service Life of Water-Loop Heat Pumps

by Mukesh K. Khattar, Customer Systems Division

The competition between electric heat pumps and other sources of heating and cooling for residential and commercial space involves many factors. One prominent issue is that of reliability and longevity. Competitors have often claimed that the heat pump is an unreliable, short-lived piece of equipment, lasting only seven to eight years. EPRI studies have demonstrated that claim to be untrue for both residential and commercial heat pumps. This article reports on one of those efforts—a pilot study of water-loop heat pumps (WLHPs) in commercial buildings (RP2480-6). The issue of reliability and resulting maintenance costs is important for commercial heat pumps—and even more important can be the loss of productivity due to downtime.

ABSTRACT *Water-loop heat pump systems are a low-first-cost, versatile, energy-efficient option for commercial space conditioning. To develop information on the reliability and longevity of these systems, EPRI sponsored a pilot survey of service records of water-loop heat pumps in commercial office buildings. The records showed that very few of the heat pumps in the sample had been replaced in their entirety. The researchers went on to examine the service records of the units' compressors and found this key replaceable system component to have a long service life.*

A WLHP system consists of a pipe loop in which water is circulated; heat pumps, one for each thermal zone, which use the water in the piping as a heat source or sink; some means of rejecting heat from the water, usually a cooling tower; and some means of adding heat to the water, usually a boiler (Figure 1). Because the heat pumps do the heating and cooling, a two-pipe (supply and return) distribution system can be used to provide simultaneous heating and cooling capability. The boiler and the cooling tower maintain the temperature of the water in the loop between 60°F and 90°F, which allows the piping to be uninsulated. The use of an uninsulated, two-pipe distribution system yields substantial installed-cost savings in comparison with the insulated, four-pipe distribution system required for providing simultaneous heating and cooling capability with a chiller/boiler system.

An example indicates how a WLHP system operates: in the winter the heat pump units on the perimeter of a building will be heating, extracting heat from the water loop, while units in the core of the building will be cooling, adding heat to the loop. This simultaneous heating and cooling of the loop provides for heat recovery and offsets operation of the boiler and the cooling tower, thus resulting in energy-efficient system operation.

WLHP systems offer flexibility in installation and in the configuring of occupied space. The heat pumps can easily be fit into most commercial buildings, since they are available in a wide variety of sizes and configurations. For example, small console units can be sited on a building's perimeter, in the occupied space; horizontal units can be mounted in the ceiling space; and large core units can be sited in machine rooms. Since the units do not have to be installed until the space is ready to be occupied, cash flow for capital expenditures is optimized.

WLHPs provide heating or cooling only as required by the individual space controls, thus affording maximum flexibility and comfort. Also, they use HCFC-22, a refrigerant that has only one-twentieth of the ozone-depletion potential of CFC-11 or CFC-12, the refrigerants used in many chillers.

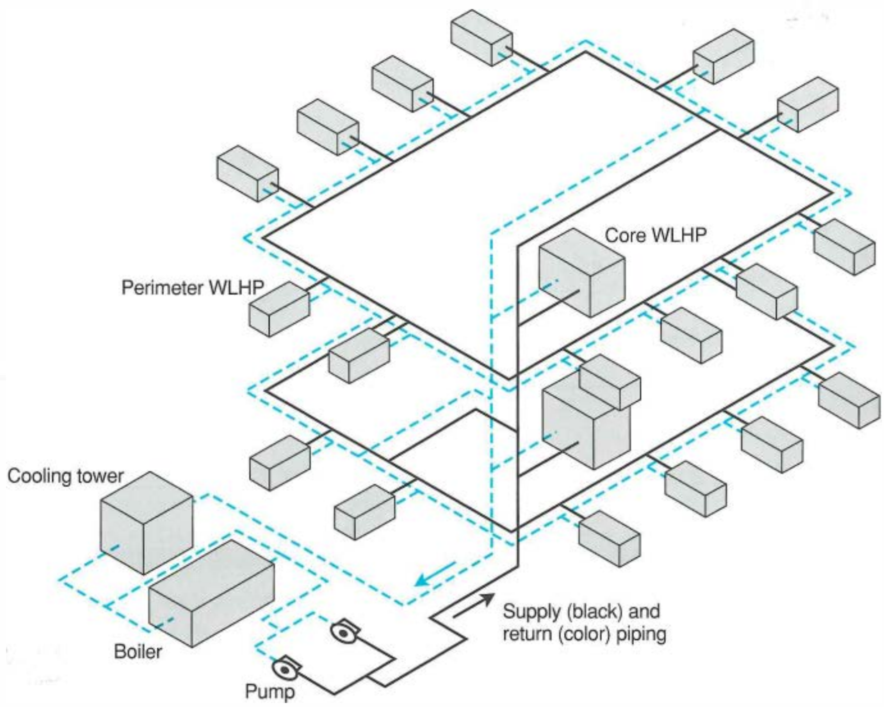
Because of the important advantages WLHP systems offer, EPRI has performed extensive research in recent years to enhance and characterize their performance. As part of this work, the pilot study under RP2480-6 (documented in CU-6739) estimated the median service life of commercial water-loop heat pumps.

On the basis of a survey of contractors and a review of their WLHP service records, the study focused on a contractor in Stamford, Connecticut, who was responsible for servicing WLHPs in many buildings and kept detailed service records for these units. His extensive records over the period 1977–1988 showed that WLHPs were rarely replaced in their entirety for service-related reasons. In light of this fact, the researchers decided to study the replacement of a key heat pump component, the compressor. Compressors were selected because they are costly to replace and because their replacement is covered by an extended warranty (usually five years), which ensured accurate service records and unit identification through serial numbers.

The commercial buildings covered in the study use large numbers of small-capacity (0.75-ton to 1-ton), console-type perimeter WLHPs, typically placed in individual offices, and smaller numbers of larger (7.5-ton to 20-ton), vertical core WLHPs, generally ducted to supply the core space of a building. The researchers obtained data from work order and warranty invoice files, which are kept for all buildings for which the service contractor has maintenance contract or warranty responsibility. The analysis covered 1700 work orders, representing service action on 2820 perimeter-unit compressors and 518 core-unit compressors.

The methodological approach taken in the commercial WLHP study was similar to that of recent EPRI studies of the reliability of residential heat pumps. Using service records and survey data, those residential studies applied actuarial methods to estimate median service life—which is defined as the age at which 50% of the original units in a population or sample have been replaced and 50% remain in service. In contrast to this approach is the use of informal, Delphi survey techniques to estimate the average age at replacement. The distinction is simple but fundamental: actuarial methods use data pertaining to the operation of an entire population or sample, including units that have not been replaced, whereas Delphi methods use only the data that describe the subset of the population or sample that has been replaced.

Figure 1 Typical configuration of a water-loop heat pump system in a commercial building. The many small-capacity, console-type perimeter units serve individual offices, and the larger units supply the building core. This technology offers several advantages for commercial space conditioning, including design flexibility, heat recovery, and energy efficiency.



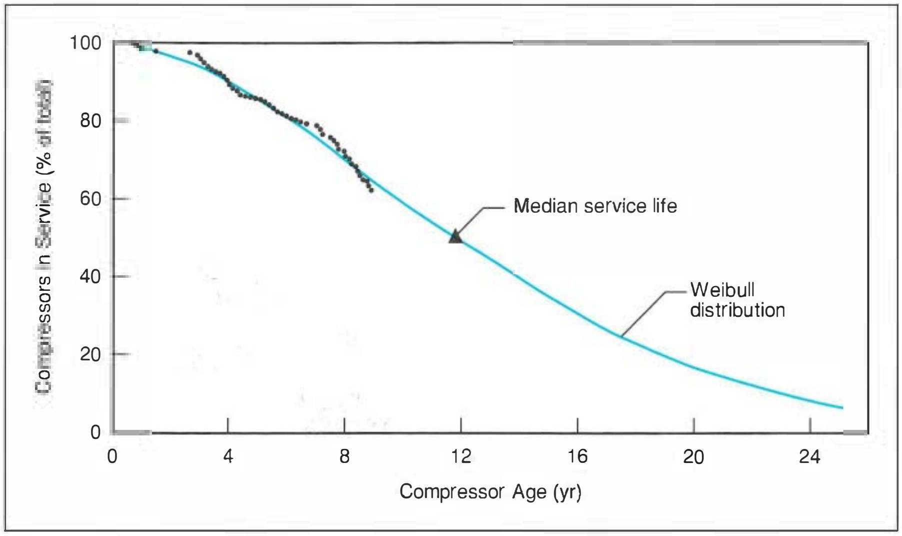
EPRI's residential work did not require extrapolation of the data to estimate median service life, since the data covered a sufficient number of heat pumps for a long enough time that more than 50% of the units had been replaced. For one population of residential heat pumps analyzed, the median service life was found to be 20 years; another study, which focused on compressors in a different sample of residential units, found the median service life of that component to be 14.5 years.

In the commercial WLHP reliability study, most of the compressors were still operating nine years after being installed (the longest period for which data were available for any single compressor). Hence extrapolation of the data was necessary to estimate the median compressor service life. Standard reliability estimation techniques using Weibull distributions were employed because of the long extrapolations required and because of the conservatism of the Weibull approach.

Of the original core-unit compressors, 73% were still operating nine years after being installed. For this population, the Weibull analysis estimated a median service life of 12 years (Figure 2). Of the original perimeter-unit compressors, 94% were still operating after nine years; the median service life for this population was estimated to be 47 years. Further investigation is necessary in order to explain the difference between the estimated service lives of core and perimeter WLHP compressors.

The *Systems and Applications Handbook* (1987) of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) reports a median service life of 19 years for water-source heat pump units. This figure is based on survey information dating from the late 1970s and covering water-source

Figure 2 Percentage of core-unit compressors remaining in service by compressor age. Extrapolation of the data using a Weibull distribution gives a median service life of 12 years.



heat pump unit replacement for any reason. However, WLHPs have been installed only since the early to mid-1960s, and very few have been replaced. For the WLHP population in the EPRI pilot study, the median service life of complete units is clearly much longer than the 19 years reported by ASHRAE.

On the basis of the pilot study, it can be concluded that the median service life of WLHPs is as long as, or longer than, those of other competitive options. Therefore, the issue of reliability should not in any sense restrict selection of WLHP systems—in fact, it may favor their selection. EPRI-sponsored researchers are continuing the reliability study, examining service records generated since the initial survey was completed almost three years ago, as well as service records for other WLHP configurations and locations.

Health Studies

Health Concerns About Short SO_2 Exposures

by Ronald Wyzga, Environment Division

Clinical studies in which asthmatics are observed under controlled laboratory conditions indicate that asthmatics may experience temporary pulmonary symptoms during exercise and that exposure to sulfur dioxide (SO_2) may aggravate these symptoms. Researchers under RP2155-1 report statistically significant responses among asthmatics at SO_2 levels of 0.4 ppm or greater. These responses include changes in specific airway resistance (SRaw), a measure of transient lung function, and in symptoms (measured before and after SO_2 exposure).

To determine whether exposure to an air pollutant adversely affects public health, it is necessary to consider both the frequency and magnitude of the potential responses and then find a way to assess whether, and to what degree, these responses are harmful. Under RP940-5, an EPRI project team developed a method that integrates the distribution of SO_2 concentrations over time and space with clinically derived dose-response relationships and with information on the likelihood that exercising asthmatics will be exposed. Using this method, researchers can estimate the likelihood that respiratory symptoms will occur in populations at risk. They can then compare these results with the subjects' baseline responses to help determine the adversity of the estimated responses.

Assessing risk

Under RP2155-1, researchers studied 40 asthmatics to estimate dose-response relationships upon SO_2 exposure. One challenge was to define a reliable indicator of changes in health status. Neither airway resistance nor symptomatology measures alone were considered sufficient for this purpose. For example, because airway resistance measures are inherently variable, an SRaw increase can simply reflect random variation. In addition, the clinical significance of such measures is unclear if the subject experiences no discomfort or if the change is readily reversible. Two- to threefold changes in SRaw are common in asthmatic subjects. In turn, symptomatic responses are subjective by nature and therefore do not necessarily reflect objective changes.

Given the limitations of these measures, the researchers defined a combined response measure that takes account of symptomatic changes only when they are accompanied by a significant increase in an objective physiological measure—specifically, a doubling of SRaw. The impact of this assumption was tested and found not to change the overall study conclusions. The study considered two levels of symptomatic response for various SO_2 exposures: responses that were annoying and responses that were severe enough to limit performance.

To estimate the potential exposure of sensitive subjects living near power plants, the researchers used a dispersion model that considers meteorological and emissions data in calculating SO_2 concentrations for each hour of the year. They selected two of the country's largest SO_2-emitting power plants, divided the area around each plant into a polar coordinate grid system, and then estimated SO_2 concentrations for the center of each grid sector for every hour of the year. All the sectors of each grid were within a 25-mile radius of the plant; beyond that distance, the calculations showed no hourly SO_2 concentrations greater than 0.25 ppm.

Because the clinical studies examined responses to 5 minutes of SO_2 exposure, the researchers converted the hourly SO_2 values to concentration estimates based on 5-minute averaging times. They constructed conditional probability distributions of 5-minute concentrations for given hourly levels by assuming the 5-minute and hourly SO_2 concentrations to be distributed normally.

The number of asthmatics in each grid sector was calculated by taking the product of the number of people in the sector and the asthma prevalence rate (adjusted for age, sex, and race distribution) in the power plant's geographic region. In the case of Plant A, a total of 64,004 people lived within the study area, and the asthma prevalence rate was 2.88%, giving an estimate of 1843 asthmatics. In the case of Plant B, 39,682 people lived within the study area, and the asthma prevalence rate was 2.44%, yielding an estimate of 968 asthmatics.

The literature provides little information about the probability that asthmatics will be outside and exercising. Thus, the project team surveyed asthmatics to estimate these values. The probability of individuals exercising strenuously outdoors for at least 10 minutes was reported by time of day and by day of the week for the month of August. August values provide a reasonable upper bound for this risk analysis because both short-term SO_2 concentrations and activity patterns tend to be highest during the summer.

Estimating asthmatics' expected risk from exposure to SO_2 called for constructing dose-response curves for both the "annoying" and "performance-limiting" levels of response. This was done separately for each symptom by fitting an equation that uses an arc sine transformation to the response probabilities at successive SO_2 levels. This transformation is used to stabilize variance when deriving a continuous dose-response curve from probability data. With this technique, the researchers were able to determine response probabilities for the SO_2 level for each 5-minute period of the year at each location within the study areas.

For each power plant, Table 1 presents estimates of SO_2-induced symptomatic responses coincident with a doubling of SRaw. (Specifically, it shows the number of 5-minute periods in a year when a symptom and a 100% SRaw increase occur simultaneously—periods designated coincidence periods.) Estimates were made for each respiratory symptom and for any combination of symptoms

Table 1
ANNUAL INCIDENCES OF SO_2-INDUCED PULMONARY SYMPTOMS

	Plant A		Plant B	
Symptom	Annoying Level	Limiting Level	Annoying Level	Limiting Level
Coughing	42.6	3.0	27.4	2.2
Sputum	21.5	0.0	15.4	0.0
Shortness of breath	120.4	15.4	66.7	8.1
Wheezing	99.3	20.0	53.8	10.9
Substernal soreness	38.7	0.0	23.2	0.0
Chest tightness	165.7	20.0	88.1	10.9
Any symptoms	186.0	24.3	98.9	13.6

Note: The table records the number of 5-minute periods during which a symptomatic response coincides with a doubling of SRaw.

ABSTRACT *Past laboratory studies have shown that exercising asthmatics can have temporary pulmonary symptoms upon exposure to sulfur dioxide. However, the results of these studies are inconclusive because of the subjective nature of people's experiences of symptoms and because of the difficulty of determining the adversity of health effects. EPRI-sponsored researchers have developed a methodology that reduces some of these difficulties and have used it to perform a risk analysis for asthmatics living near two U.S. power plants. The analysis found a very low probability of increased pulmonary symptoms due to SO_2 emissions. Information from studies like this can help policymakers evaluate proposed air quality standards.*

("any symptoms"), for both the annoying and performance-limiting response levels. Thus, during the year for which meteorological data are available, the asthmatic population living within 25 miles of Plant A will experience no more than 186 annoying incidences of increased symptoms. (One person may experience more than one incidence.)

Defining adverse health effects

The asthmatic subjects recruited to generate the dose-response curves were surveyed to determine their daily activity levels and patterns of symptom response. The survey instrument consisted of a background questionnaire and a three-day diary. Participants were asked to fill out the diary every hour during their waking hours and to provide overnight summaries. In addition, they completed a daily summary that compared their activities and symptoms to those of other days. The diaries provided information about the subjects' symptomatic responses, including descriptions of their breathing during each activity and whether this breathing was an asthma symptom, descriptions of other asthma symptoms experienced during each activity, and reports of asthma attacks during each activity.

Table 2 summarizes the subjects' symptom frequencies. For instance, the survey participants experienced wheezing 10.7% of their waking hours. Asthma symptoms were prevalent, as indicated by the relatively frequent occurrence of "any symptoms" and lower respiratory symptoms. In particular, wheezing, coughing, and chest tightness—which participants generally considered to be asthma symptoms—were fairly common.

Table 2
ASTHMATICS' REPORTS OF SYMPTOM FREQUENCY

Symptom	Percentage of Waking Hours
Wheezing	10.7
Coughing	10.1
Chest tightness	11.7
Shortness of breath	4.2
Substernal irritation	3.4
Fast breathing	4.5
Shallow breathing	3.4
Heavy breathing	6.1
Lower respiratory symptoms	19.3
Other asthma symptoms	4.0
Any symptoms	26.2
Asthma attack	3.2

Analysis of the symptomatic and biological responses observed in clinical studies of exercising asthmatics exposed to SO_2 requires difficult judgments about medical significance and adversity. Scientists need as much information as possible to aid this judgment. Results from complementary chronic animal and epidemiology studies could help interpret the biological response data from human clinical studies; unfortunately, no unambiguous animal or epidemiology studies are currently available to guide this work.

An alternative approach to defining adversity is to compare experimental observations of responses with data on the underlying variability of responses in the absence of the study exposures. Fortunately, the diary study of exposed subjects produced good background data for use in such comparisons with human clinical data.

The annual risk that asthmatics will experience an SO_2-induced symptom response because of a nearby power plant is equal to the number of SO_2-induced responses expected during the year. This can be expressed as a response rate by dividing it by the total number of asthmatic-hours (i.e., the number of asthmatics in the study area multiplied by the number of waking hours in a year, assuming 16 waking hours per day). Table 3 shows the response rates from the EPRI study for symptoms experienced at the annoying level. (To calculate these rates, the estimates of 5-minute coincidence periods from Table 1 were divided by the total waking asthmatic-hours for each study area, and the results multiplied by 100 to yield percentages.)

The response rates are very low. For example, the rate for "any symptoms" is less than 2×10^{-3} percent (2 in 10,000) for asthmatics living around either plant. While these rates provide risk estimates standardized for the population density in the study areas, caution is necessary in applying these values to other power plants, which may have different emission patterns.

Table 3
RATES OF SO_2-INDUCED PULMONARY SYMPTOMS

Symptom	Response Rate (%) Plant A	Response Rate (%) Plant B
Coughing	3.96×10^{-4}	4.85×10^{-4}
Sputum	2.00×10^{-4}	2.72×10^{-4}
Shortness of breath	1.12×10^{-3}	1.18×10^{-3}
Wheezing	9.23×10^{-4}	9.52×10^{-4}
Substernal soreness	3.60×10^{-4}	4.11×10^{-4}
Chest tightness	1.54×10^{-3}	1.56×10^{-3}
Any symptoms	1.73×10^{-3}	1.75×10^{-3}

Note: Response rate equals the percentage of waking asthmatic-hours during which incidences of annoying pulmonary symptoms and a doubling of SRaw occur. The analysis assumes no more than one 5-minute coincidence period per hour; to assume otherwise would reduce the response rate.

The adversity of these risks can be assessed by comparing them with asthma symptom responses exhibited in the absence of SO_2. As Table 2 shows, the survey participants reported experiencing "any symptoms" during some 26% of waking hours and lower respiratory symptoms during some 19% of waking hours. Thus, the incremental risk due to SO_2 exposure (the values in Table 3) is more than four orders of magnitude lower than the baseline risk from everyday life.

In summary, this analysis of two of the largest rural power plants in the United States indicates that the probability that an asthmatic will experience symptoms as a result of power plant emissions is less than 2 in 10,000 in a given hour. This finding reflects the facts that the relatively high SO_2 concentrations necessary to elicit responses occur only rarely and over relatively small areas, and that an asthmatic is unlikely to be outdoors exercising when these relatively high SO_2 levels occur.

Comparing these symptomatic responses with those likely to occur in the absence of SO_2 cannot in itself define adversity, but it does facilitate that judgment. Results from this type of study should help national and state decision makers evaluate the need for short-term SO_2 air quality standards to protect exercising asthmatics.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Innovative Rate Survey (RP2343-7)	$107,100 11 months	Casazza, Schultz & Associates/*W. LeBlanc*
Nickel-Iron Battery Pilot Plant (RP2415-23)	$3,774,200 22 months	Eagle-Picher Industries/ *R. Swaroop*
DSM Distribution Impacts Study (RP2548-9)	$82,000 17 months	Energy & Environmental Economics/*P. Meagher*
Chrysler TEVan: Phase 2 Development (RP2664-23)	$5,000,000 28 months	Chrysler Corp./*G. Purcell*
Field Evaluation of Packaged Rooftop Air Conditioning Units (RP2732-41)	$90,000 5 months	R. Douglas Stone & Associates/*R. Wendland*
Survey of Utility DSM Activities (RP2884-2)	$144,600 13 months	Plexus Research/ *P. Meagher*
Industrial DSM Analysis and Support (RP2885-2)	$218,500 26 months	Resource Dynamics Corp./*P. Meagher*
Antifreeze for Ground-Source Heat Pumps (RP2892-18)	$125,700 14 months	Oklahoma State University/*P. Joyner*
Development and Commercialization of Active Power Line Conditioner (RP2918-9)	$214,900 5 months	Westinghouse Electric Corp./*B. Banerjee*
Electrical Systems		
EMF Workstation (RP2942-11; concurrent with Environment RP2966-5)	$92,400 16 months	Enertech Consultants/ *G. Ben-Yaacov*
Development of Advanced Simulation Techniques for Gate-Turnoff Thyristors (RP3115-3)	$85,000 9 months	Drexel University/ *H. Mehta*
Advanced Static VAR Generator for Distribution Systems (RP3155-4)	$129,800 14 months	PSM Technologies Corp./ *H. Mehta*
TLWorkstation™ User Support (RP3187-4)	$93,500 12 months	Power Computing Co./ *P. Lyons*
Environment		
Development of a CO_2 Pressure Technique for Chemical Stabilization of Alkaline Solid Wastes From Clean Coal Technologies (RP2485-21)	$106,800 26 months	University of Wyoming/ *M. Elrashidi*
Biotransformation Studies of Organic Substances (RP2879-9)	$819,300 24 months	Utah State University/ *I. Murarka*
Environmental Distribution of Organic Substances at Utility Sites (RP2879-12)	$2,911,800 42 months	Atlantic Environmental Services/*A. Quinn*
Electrical Injury: Mechanisms of Lethal Cellular Damage (RP2914-3)	$150,000 12 months	University of Chicago/ *W. Weyzen*
EMF Workstation (RP2966-5; concurrent with Electrical Systems RP2942-11)	$92,400 16 months	Enertech Consultants/ *G. Ben-Yaacov*
Exploratory and Applied Research		
Electric Field Microsensor (RP8004-5)	$293,500 35 months	Brown University/*J. Stein*
Non-Newtonian Slurry Flows (RP8006-1)	$98,300 11 months	Southwest Research Institute/*J. Maulbetsch*
Reversibility of Combustion Processes (RP8006-19)	$119,900 24 months	Dartmouth College/ *J. Maulbetsch*
Generation and Storage		
Advanced 9Cr/12Cr Materials for Thick-Section Boiler Components (RP1403-50)	$460,000 52 months	National Power/*W. Bakker*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Header Feedwater Heater Retrofit (RP1403-57)	$441,000 7 months	Long Island Lighting Co./ *J. Bartz*
Study of Condensing Heat Transfer (RP1689-25)	$349,000 17 months	Rochester Institute of Technology/*J. Tsou*
Evaluation of Rock Caverns and Porous Media Sites for CAES Plants in Indiana (RP2615-13)	$56,400 5 months	Fenix & Scisson/*B. Mehta*
Analysis and Demonstration of a Utility Moisture Meter Application (RP3123-3)	$62,900 25 months	Tennessee Valley Authority/*D. O'Connor*
Digital Control System–PC Simulation Interface (RP3152-2)	$215,500 21 months	Science Applications International Corp./ *M. Divakaruni*
Ceramic Filter Elements for High-Temperature Gases (RP3160-1)	$94,100 24 months	Aachen University of Technology/*M. Epstein*
Low-Cost Construction Materials to Improve Construction Technologies (RP3176-1)	$61,800 25 months	University of Wisconsin, Milwaukee/*D. Golden*
Improved Superclean CrMoV Steel (RP3199-13)	$118,400 22 months	Japan Steel Works America/*R. Jaffee*
Integrated Energy Systems		
System Design for Bulk Power Planning (RP3145-1)	$150,100 12 months	Strategic Decisions Group/*H. Mueller*
Sulfidation and Corrosion of Ferrous Alloys: Surface Studies (RP3199-11)	$301,300 37 months	University of North Texas/ *J. Stringer*
Nuclear Power		
Evaluation of Pump Shaft Cracking (RP2455-24)	$50,000 5 months	Structural Integrity Associates/*T. Griesbach*
Digital Control System Verification and Validation Methodology (RP3008-2)	$169,800 12 months	Martin Marietta Energy Systems/*S. Bhatt*
Electromagnetic Acoustic Transducers to Test for Corrosion in Mark I Containment Vessels (RP3148-5)	$59,600 18 months	Innovative Sciences/ *M. Avioli*
Enhancement of the EDDY-2D Code (RP3148-7)	$137,400 13 months	Washington State University/*M. Avioli*
Specification for Use of Alloy 750 in LWRs (RP3154-4)	$266,000 45 months	Stone & Webster Engineering Corp./ *L. Nelson*
Regionalization of Seismic Attenuation (RP3180-1)	$231,400 17 months	Pacific Engineering & Analysis/*J. Schneider*
Regionalization of Ground Motion Attenuation (RP3180-2)	$198,900 14 months	Woodward-Clyde Consultants/*J. Schneider*
Standardization of Snubber Functional Testing Method (RP3182-1)	$154,800 12 months	Lake Engineering Co./ *Y. Tang*
Plant Process Computer Upgrade and Replacement Guidelines (RP3208-1)	$90,800 10 months	Science Applications International Corp./ *S. Bhatt*
Remedial Measures for Primary-Water Stress Corrosion Cracking (RP3223-1)	$54,600 6 months	Dominion Engineering/ *R. Pathania*
Advanced Light Water Reactor Requirements Integration (RP3260-1)	$397,400 15 months	Tenera LP/*S. Gray*
Tube-Plugging Limits for Outside-Diameter SCC at Tube Support Plate Intersections of PWR Steam Generators (RPS404-29)	$578,900 10 months	Westinghouse Electric Corp./*L. Williams*
Reference Electrode Qualification Testing for In Situ Application in PWR Steam Generators (RPS407-41)	$64,200 5 months	NWT Corp./*P. Paine*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Reports will be provided to nonmember U.S utilities only upon purchase of a license, the price for which will be equal to the price of EPRI membership. Others pay the listed price. Research Reports Center will send a catalog of EPRI reports on request. To order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

CUSTOMER SYSTEMS

Retrofitting Utility Power Plant Motors for Adjustable Speed: Field Test Program
CU-6914 Final Report (RP1966-6, RP2951-6); $200
Contractor: Bechtel Group, Inc.
EPRI Project Manager: M. Samotyj

Market Penetration of New Technologies, Programs, and Services
CU-7011 Final Report (RP2864-1); $200
Contractor: Research Triangle Institute
EPRI Project Manager: T. Henneberger

Impact of Direct Load Control Programs: A Duty-Cycle Approach, Vols. 1 and 2
CU-7028 Final Report (RP2342-8); $200 each volume
Contractor: Quantum Consulting, Inc.
EPRI Project Managers S. Braithwait, P Meagher

Energy Use and Changing Lifestyles
CU-7069 Final Report (RP2927-3, RP3165); $200
Contractor: Lawrence Berkeley Laboratory
EPRI Project Managers: L. Lewis, P. Cleary

Field Testing of a Dual-Fuel Rooftop Heat Pump
CU-7084 Final Report (RP2891-6); $200
Contractor: The Fleming Group
EPRI Project Managers: M. Blatt, J. Kesselring

Proceedings: Meeting Customer Needs With Heat Pumps—1989
CU-7174 Proceedings (RP2597-9); $200
Contractor: Policy Research Associates, Inc.
EPRI Project Manager: M. Blatt

Proposed Testing Protocols for Commercial Kitchen Ventilation Research
CU-7210 Final Report (RP2890-8); $200
Contractor: Underwriters Laboratories, Inc.
EPRI Project Manager: K. Johnson

Simulated Attic Radiant Barrier Performance
CU-7220 Final Report (RP2034-36); $200
Contractor: Davis Energy Group, Inc.
EPRI Project Manager: J. Kesselring

ELECTRICAL SYSTEMS

TLWorkstation™ Code, Version 2.0, Vol. 6: TLOP/TLOPWT/SAGT Manual (Revision 1)
EL-6420 Final Report (RP2151-1); $200
Contractor: Power Technologies, Inc.
EPRI Project Manager: R. Kennon

Transmission Cable Magnetic Field Research
EL-6759-D Final Report (RP7898-21); $500
Contractor: Power Technologies, Inc.
EPRI Project Manager: J. Shimshock

Structure and Properties of Superconducting Ceramics
EL-7002 Interim Report (RP7911-5); $200
Contractor: National Institute of Standards and Technology
EPRI Project Manager: W. Bakker

Proceedings: EPRI 1990 PCDF/PCDD Workshop
EL-7073 Proceedings (RP2028-21); $200
Contractor: Twin City Testing Corp.
EPRI Project Manager: G. Addis

Evaluation of Sensitive Diagnostic Techniques for Cable Characterization, Vol. 1: Nine Diagnostic Tools
EL-7076 Final Report (RP7897-1); $200
Contractor: University of Connecticut
EPRI Project Manager: B. Bernstein

Evaluation of Packed-Column Gas Chromatography With Electron Capture Detector Quantitation for Polychlorinated Biphenyls
EL-7160 Final Report (RP2028-15); $200
Contractor: Midwest Research Institute
EPRI Project Manager G. Addis

A Knowledge-Based Support System for Voltage Collapse Detection and Prevention
EL-7168 Final Report (RP2473-36); $200
Contractor: Howard University
EPRI Project Manager: R. Adapa

ENVIRONMENT

The EMDEX Project: Technology Transfer and Occupational Measurements, Vols. 1–3
EN-7048 Interim Report (RP2966-1); $200 each volume
Contractor: T. Dan Bracken, Inc.
EPRI Project Manager: S. Sussman

Demographic Modeling of Selected Fish Species With RAMAS
EN-7178 Final Report (RP2553); $200
Contractor: Applied Biomathematics, Inc.
EPRI Project Manager: A. Silvers

MOSES Code Version 1.0: An IBM PC Code for Predicting the Transport and Fate of Mineral Oil Spills
EN-7188 Interim Report (RP2879-2); $200
Contractor: Tetra Tech, Inc.
EPRI Project Manager: I. Murarka

EXPLORATORY AND APPLIED RESEARCH

Proceedings: Workshop on Polymers in the Generation, Storage, Transmission, and Distribution of Electric Power
ER-6982 Proceedings (RP8007-7); $200
Contractor: Johns Hopkins University
EPRI Project Manager: B. Bernstein

Seaweeds and Halophytes to Remove Carbon From the Atmosphere
ER/EN-7177 Final Report (RP8011-3); $200
Contractor: University of Arizona
EPRI Project Manager: L. Pitelka

Intergranular Corrosion of Stainless Steel, Vols. 1 and 2
ER-7247 Final Report (RP8002-1); $200 each volume
Contractor: AEA Industrial Technology, UKAEA
EPRI Project Manager: D. Cubicciotti

GENERATION AND STORAGE

Remaining-Life Estimation of Boiler Pressure Parts, Vol. 5: Creep-Fatigue Interaction
CS-5588 Final Report (RP2253-1); $400
Contractor: ABB Combustion Engineering Systems
EPRI Project Manager: R. Viswanathan

Laboratory Guidelines and Procedures, Trace Elements in Coal, Vol. 5: Analytic Procedures for Trace Elements
CS-5644 Interim Report (RP1400-4, -6; RP2704-1); $200
Contractor: CQ Inc.
EPRI Project Managers: H. Lebowitz, D. O'Connor

Cool Water Coal Gasification Program: Final Report
GS-6806 Final Report (RP1459); $2000
Contractors: Cool Water Coal Gasification Program; Radian Corp.
EPRI Project Managers: E. Clark, N. Holt

Assessment and Guide for Meeting Dissolved Oxygen Water Quality Standards for Hydroelectric Plant Discharges
GS-7001 Final Report (RP2694-8); $200
Contractor: Aquatic Systems Engineering
EPRI Project Manager: D. Rastler

Improvement of the Exhaust Flow of a Low-Pressure Turbine
GS-7003 Final Report (RP1878-5); $1000
Contractors Lehigh University; IMO Delaval
EPRI Project Manager J. Tsou

Retrofits for Improved Heat Rate and Availability: Circulating-Water Heat Recovery Retrofits
GS-7009 Interim Report (RP1403-16); $200
Contractor: Gilbert/Commonwealth, Inc.
EPRI Project Manager: J. Bartz

The Production of Methanol by the Brookhaven National Laboratory Process
GS-7038 Final Report (RP2146-6); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: W. Weber

Proceedings: Eighth Particulate Control Symposium, Vols. 1 and 2
GS-7050 Proceedings (RP1129-18); $250
EPRI Project Managers: R. Chang, R. Altman

Shell Coal Gasification Project: Gasification of Six Diverse Coals
GS-7051 Interim Report (RP2695-1); $300
Contractor: Shell Development Co.
EPRI Project Manager N. Stewart

Options for Handling Noncombustion Waste
GS-7052 Final Report (RP3006-2); $500
Contractors Mittelhauser Corp.; Roy F. Weston, Inc.; Precor Corp.
EPRI Project Manager: M. McLearn

Superconducting Magnetic Energy Storage (SMES), Vol. 1: Basic R&D, 1984–1985
GS-7053 Final Report (RP2572-2); $200
Contractor: University of Wisconsin, Madison
EPRI Project Manager: R. Schainker

Internal-Combustion Engine NO_x Control
GS-7054 Final Report (RP2936-1); $500
Contractor: Radian Corp.
EPRI Project Manager: H. Schreiber

Performance and Durability Evaluation of 3M High-Temperature Nextel Filter Bags
GS-7055 Final Report (RP1336-16); $200
Contractor: University of North Dakota, Energy & Environmental Research Center
EPRI Project Manager: S. Drenker

Evaluation of Oil-Fired Gas Turbine Selective Catalytic Reduction (SCR) NO_x Control
GS-7056 Final Report (RP2936-1); $500
Contractor: Radian Corp.
EPRI Project Manager: H. Schreiber

Market Opportunities for Fly Ash Fillers in North America
GS-7059 Final Report (RP2422-20); $200
Contractor: Kline & Company, Inc.
EPRI Project Manager: D. Golden

Life Optimization for Fossil Fuel Power Plants
GS-7064 Final Report (RP2596-10); $1000
Contractors: Daedalus Associates, Inc.; El International; Failure Analysis Associates, Inc.; General Physics Corp., Heat Exchanger Systems; Temple, Barker & Sloane, Inc.; Stone and Webster Engineering Corp.
EPRI Project Manager: B. Dooley

Physiochemical Principles of Coal-Water-Slurry Gasifier Feedstocks
GS/ER-7068 Interim Report (RP8006-6); $200
Contractor: Adelphi University
EPRI Project Manager: W. Weber

User's Guide to DYNASTORE: A Computer Model for Quantifying Dynamic Energy Storage Benefits
GS-7070 Final Report (RP3116-1); $200
Contractor: Electric Power Consulting, Inc.
EPRI Project Manager: B. Louks

Development of Warranties for Combustion Turbine Procurement
GS-7075 Final Report (RP2774-6); $500
Contractor: ARINC Research Corp.
EPRI Project Manager: J. Weiss

Data Acquisition for Photovoltaic Power Plants
GS-7082 Interim Report (RP1607-6); $200
Contractor: New Mexico State University
EPRI Project Manager: J. Schaefer

Testing, Monitoring, and Maintenance of Aboveground Storage Tanks
GS-7086 Final Report (RP2795-1); $200
Contractor: Roy F. Weston, Inc.
EPRI Project Manager: M. McLearn

A RAM Analysis of Consolidated Edison's Gowanus and Narrows Gas Turbine Power Plants
GS-7087 Final Report (RP2989-2); $200
Contractor: Science Applications International Corp.
EPRI Project Manager: R. Frischmuth

Development of Zinc-Bromine Batteries for Utility Applications: Commercialization Task
GS-7093 Final Report (RP2123-3); $200
Contractor: Energy Research Corp.
EPRI Project Manager: R. Weaver

Proceedings: DOE/EPRI Beta (Sodium/Sulfur) Battery Workshop VIII
GS-7163 Proceedings (RP1084-33); $200
EPRI Project Manager: R. Weaver

Atmospheric Fluidized-Bed Combustion Performance Guidelines
GS-7164 Final Report (RP2683-15); $200
Contractor: Ernest Sotelo
EPRI Project Manager: T. Boyd

Use of Coal Ash in Highway Construction: Michigan Demonstration Project
GS-7175 Interim Report (RP2422-7); $200
Contractor: Consumers Power Co.
EPRI Project Manager: D. Golden

Condenser Targeted-Chlorination Demonstration at Brayton Point Station, Unit 2
GS-7181 Final Report (RP2300-2); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: W. Chow

Interim Operations Report for Atmospheric Fluidized-Bed Combustion Conversion at Northern States Power Company
GS-7182 Interim Report (RP2628-6); $200
Contractor: Hamilton Maurer International, Inc.
EPRI Project Manager: J. Stallings

Long-Term Leaching Tests With High Ash Fusion Maryland Coal Slag
GS-7185 Final Report (RP2659-8); $200
Contractor: Tennessee Valley Authority
EPRI Project Manager: N. Hertz

Economic Evaluation of Flue Gas Desulfurization Systems, Vol. 1
GS-7193 Final Report (RP1610-6); $1000
Contractor: United Engineers and Constructors, Inc.
EPRI Project Manager: P. Radcliffe

Ceramic Composites for Power Generation Combustion Turbines
GS-7225 Final Report (RP2608-2); $200
Contractor: General Electric Co.
EPRI Project Manager: W. Bakker

Compatibility of Admix and Synthetic Liner Materials With Clean Coal Technology By-products
GS-7226 Topical Report (RP2708-1); $200
Contractor: Battelle, Pacific Northwest Laboratories; Hart Crowser, Inc.
EPRI Project Manager: D. Golden

High-Performance, Long-Life Sodium/Sulfur Cells
GS-7229 Final Report (RP128-8); $200
Contractor: Ceramatec, Inc.
EPRI Project Manager: W. Bakker

Summary Memorandum: EPRI Copper Indium Diselenide Scoping Workshop
GS-7231 Special Report; $200
EPRI Project Manager: T. Peterson

Proceedings: Transition Strategies to Hydrogen as an Energy Carrier—First Annual Meeting of the National Hydrogen Association
GS-7248 Proceedings (RP1086-22); $200
Contractor: Technology Transition Corp.
EPRI Project Manager: B. Mehta

INTEGRATED ENERGY SYSTEMS

Strategies for Coping With Drought, Part 3: Planning and Operation of Hydrothermal Generation Systems
P-6465 Final Report (RP2194-1); $200
Contractor: University of Washington
EPRI Project Manager: E. Altouney

Imported LNG as an Alternative Fuel
OCSP-6871 Final Report (RP3201-2); $200
Contractor: Jensen Associates, Inc.
EPRI Project Manager: H. Mueller

NUCLEAR POWER

Boric Acid Application Guidelines for Intergranular Corrosion Inhibition (Revision 1)
NP-5558-M Topical Report (RPS407-35); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: P. Paine

Ultrasonic Wave Propagation in Reactor Pressure Vessel Cladded Interfaces
NP-6974 Final Report (RP2687-8); $200
Contractor: Weidlinger Associates
EPRI Project Manager: M. Avioli

Proceedings: Steam Turbine/Generator NDE Workshop
NP-6993 Proceedings (RP1570-2); $200
Contractor: J. A. Jones Applied Research Co.
EPRI Project Managers: G. Dau, S. Liu

Strain-Rate Damage Model for Alloy 600 in Primary Water
NP-7008 Final Report (RPS303-8); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: A. McIlree

Material Specification for Alloy X-750 for Use in LWR Internal Components (Revision 1)
NP-7032 Interim Report (RP2181-4); $25,000
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: J. Nelson

Aqueous Electrochemistry of Precipitation-Hardened Nickel Base Alloys
NP-7034 Interim Report (RP2181-5); $200
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: J. Nelson

Large-Eddy Simulation on Supercomputers
NP-7041 Final Report (RPS410-12); $200
Contractor: Texas A&M University
EPRI Project Manager: D. Steininger

Demonstration of a Risk-Based Approach to High-Level Waste Repository Evaluation
NP-7057 Final Report (RP3055-2); $200
Contractor: Risk Engineering, Inc.
EPRI Project Manager: R. Shaw

PWR Primary Water Chemistry Guidelines: Revision 2
NP-7077 Final Report (RP2493); $200
EPRI Project Manager: C. Wood

Instrument Air Systems: A Guide for Power Plant Maintenance Personnel
NP-7079 Final Report (RP2814-29); $9200
Contractor: BCP Technical Services, Inc.
EPRI Project Manager: B. Varma

Technical Guidance for Detection of Oil-Loss Failure of Rosemount Pressure Transmitters
NP-7121 Final Report (RP2409-6); $200
EPRI Project Manager: J. Weiss

The October 1, 1987, Whittier Earthquake: Effects on Selected Power, Industrial, and Commercial Facilities
NP-7126 Final Report (RP2848-6); $200
Contractor: EQE Engineering
EPRI Project Manager: R. Kassawara

Hot Cell Examination Results of Hafnium Control Rods From Maanshan-1 PWR
NP-7143 Final Report (RP1628); $20,000
Contractor: Institute of Nuclear Energy Research
EPRI Project Manager: O. Ozer

Guidelines for Development of In-Cabinet Amplified Response Spectra for Electrical Benchboards and Panels
NP-7146-M Final Report (RP2925-8); $200
Contractor: Stevenson & Associates, Inc.
EPRI Project Manager: R. Kassawara

Summary of BWR Owners Group Intergranular Stress Corrosion Cracking Research Program, 1979–1988
NP-7154 Final Report (RP1930-20); $10,000
Contractor: Joseph C. Danko
EPRI Project Manager: M. Behravesh

SHARP1: A Revised Systematic Human Action Reliability Procedure
NP-7183-M Interim Report (RP3206-1, -2, -3, -4); $200
Contractors: PLG, Inc.; NUS Corp.; Science Applications International Corp.; Accident Prevention Group
EPRI Project Manager: A. Singh

Review of Polyimide-Insulated Wire in Nuclear Power Plants
NP-7189 Final Report (RP1707-40); $200
Contractor: ERC Environmental and Energy Services Co.
EPRI Project Manager: G. Sliter

Nuclear Unit Operating Experience: 1987–1988
NP-7191 Final Report (RP2940-3); $10,000
Contractor: Stoller Power Division of RCG/Hagler, Bailly, Inc.
EPRI Project Manager: G. Allen

Proceedings: 1990 EPRI Workshop on Circumferential Cracking of Steam Generator Tubes
NP-7198-M Proceedings (RPS406-3); $200
Contractor: Dominion Engineering, Inc.
EPRI Project Manager: A. McIlree

Environmental Cracking of Alloy 600 in BWR Environments
NP-7199 Interim Report (RP2293-1); $200
Contractor: ABB Atom AB
EPRI Project Manager: D. Cubicciotti

Effect of Induction Heating Stress Improvement on Ultrasonic Response From Intergranular Stress Corrosion Cracking
NP-7238 Interim Report (RPC105-2); $10,000
Contractor: Ishikawajima-Harima Heavy Industries Co., Ltd.
EPRI Project Manager: M. Behravesh

Effects of Fire Suppressants on Electrical Components in Nuclear Power Plants
NP-7253 Final Report (RP2969); $25,000
Contractor: Impell Corp.
EPRI Project Manager: J. Sursock

An Evaluation of the Concept of Transuranic Burning Using Liquid Metal Reactors
NP-7261 Final Report (RP3030); $200
EPRI Project Manager: E. Rodwell

CALENDAR

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

JUNE

12–14
Upgrading Transmission Lines
Haslet, Texas
Contact: Dick Kennon, (415) 855-2311

13–14
NMAC Regional Workshop: Small Fasteners
St. Louis, Missouri
Contact: Bob Kannor, (415) 855-2018

16–21
Workshop: Radwaste
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

17–21
Transmission Line Electrical Design: ACDCLINE
Lenox, Massachusetts
Contact: Jim Hall, (415) 855-2305

18–20
Workshop: Condensate Polishing
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

20–21
Seminar: Low-Level Waste Management and Radiation Protection
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

24–26
1991 EPRI Technology Transfer Meeting
Palo Alto, California
Contact: Joanne Peterson, (415) 855-2716

26–28
Conference: Information and Automation Technology
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

26–28
Power Plant Pumps
Tampa, Florida
Contact: Susan Bisetti, (415) 855-7919

JULY

16–19
EPRI Workshop: Steam Turbine Generator NDE, Life Assessment, and Maintenance
Charlotte, North Carolina
Contact: Tom McCloskey, (415) 855-2655

23–26
Applications of Neural Networks to Power Systems
Seattle, Washington
Contact: Rambabu Adapa, (415) 855-8988

30–August 1
5th National Demand-Side Management Conference
Boston, Massachusetts
Contact: Bill LeBlanc, (415) 855-2887

AUGUST

7–9
Methodologies, Tools, and Standards for Cost-Effective, Reliable Software Verification and Validation
Chicago, Illinois
Contact: Pam Turner, (415) 855-2010

13–19
3d Fossil Plant Inspection Conference
Baltimore, Maryland
Contact: Maureen Barbeau, (415) 855-2127

SEPTEMBER

5–6
Workshop: Application of Advanced Mathematical Techniques to Power Systems
Palo Alto, California
Contact: Rambabu Adapa, (415) 855-8988

9–11
Expert Systems Applications for the Electric Power Industry
Boston, Massachusetts
Contact: Susan Bisetti, (415) 855-7919

18–20
Conference: Fossil Plant Construction
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

18–20
International Conference: Use of Coal Ash and Other Coal Combustion By-products
Shanghai, China
Contact: Dean Golden, (415) 855-2516

19–20
Magnetic Field Measurement
Lenox, Massachusetts
Contact: Greg Rauch, (415) 855-2298

25
ETADS Users Group Meeting
Dallas, Texas
Contact: Paul Lyons, (817) 439-5900

OCTOBER

8–11
1991 PCB Seminar
Baltimore, Maryland
Contact: Maureen Barbeau, (415) 855-2127

15–18
Meeting Customer Needs With Heat Pumps
Dallas, Texas
Contact: Pam Turner, (415) 855-2010

15–18
Particulate Control
Williamsburg, Virginia
Contact: Susan Bisetti, (415) 855-7919

16–18
Coal Gasification
San Francisco, California
Contact: Lori Adams, (415) 855-8763

29–November 2
Computer-Aided Control System Analysis: Classical Techniques
Birmingham, Alabama
Contact: Murthy Divakaruni, (415) 855-2409

NOVEMBER

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

5–7
Boiler Tube Failure
San Diego, California
Contact: Maureen Barbeau, (415) 855-2127

12–13
Zebra Mussels
Cleveland, Ohio
Contact: Susan Bisetti, (415) 855-7919

DECEMBER

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

11–13
Generator and Motor Workshop
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

Authors and Articles


O'Connell


Purcell


Guy


Swaroop


Torrens


Offen


Platt


Fortune

They're New! They're Clean! They're Electric! (page 4) was written by Taylor Moore, *Journal* senior feature writer, with assistance from three members of EPRI's Customer Systems Division.

Lawrence O'Connell, senior program manager for electric transportation, joined EPRI in 1985 after 30 years with Lawrence Livermore National Laboratory. An engineering graduate of the U.S. Naval Academy, he has been involved in the planning and management of research in automotive power systems and transportation since 1974.

Gary Purcell, a project manager for electric vehicle systems, joined EPRI in 1977 after 15 years as a design engineer with Lockheed Missiles & Space Company. A mechanical engineering graduate of Oklahoma State University, Purcell earned an MBA at Pepperdine University.

Jack Guy, manager of commercialization in the Customer Systems Division, joined EPRI in 1974 after 18 years with General Electric Company, where he held various positions in engineering, marketing, manufacturing, and management. Guy attended the Advanced Marketing and Management Program at Harvard University and studied engineering at Villanova and Lehigh universities. ■

The Push for Advanced Batteries (page 16) was also written by Taylor Moore, with assistance from **Robert Swaroop,** a senior project manager for EV battery systems in the Electric Transportation Program.

Swaroop joined EPRI in 1988 after 10 years as a research manager and scientist at Argonne National Laboratory, where he worked in various energy-related programs, including advanced batteries. Before that, Swaroop worked in R&D for Fairchild Semiconductor Corporation. He earned a PhD in materials science and electrochemistry at the University of Toronto and an MBA from the University of Chicago. ■

Responding to the Clean Air Challenge (page 20) was written by the newest member of the *Journal* staff, feature writer Leslie Lamarre, with the assistance of the Generation and Storage Division and the newly created Integrated Energy Systems Division.

Ian Torrens has directed the Environmental Control Systems Department since he joined the Institute in 1987. He was formerly with the Organization for Economic Cooperation and Development for 14 years, including 7 years in the Environment Directorate as head of the pollution control division. Before that, he was a researcher with the French Atomic Energy Commission.

George Offen heads the Air Quality Control Program. Before he joined the Institute in 1985, Offen was with Acurex Corporation, first as a project manager and senior staff engineer and later as the manager of energy engineering; he was involved in regulatory, research, and technology programs for reducing pollution from combustion sources and synthetic fuels processes.

Jeremy Platt is a senior project manager in the Integrated Energy Systems Division. He was previously with the Generation and Storage Division and, before that, with the Environment Division. Since joining EPRI in 1974, Platt has managed studies in energy resource assessment, fuel supply and market forecasting, and utility fuel planning issues.

Jim Fortune is a program manager in the Integrated Energy Systems Division. He joined EPRI in 1989 after nearly 10 years with Virginia Power, where he served as an engineering project manager and the director of engineering. Before that, he was the manager of system mechanical analysis for Babcock & Wilcox Company. ■

Ben Dysart: Making an Impact on Environmental Engineering (page 30) profiles a conservationist with an interesting and varied career background, including work as head of the National Wildlife Federation and currently as facility development manager for a major nationwide toxic waste disposal service. Also a member of EPRI's Advisory Council, Dysart was interviewed for this article by writer Ralph Whitaker. ■

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