Batteries for Electric Vehicles

Also in this issue • Electric Lawn Mowers • Digital Load Recognition • Ozone Research

ELECTRIC POWER RESEARCH INSTITUTE

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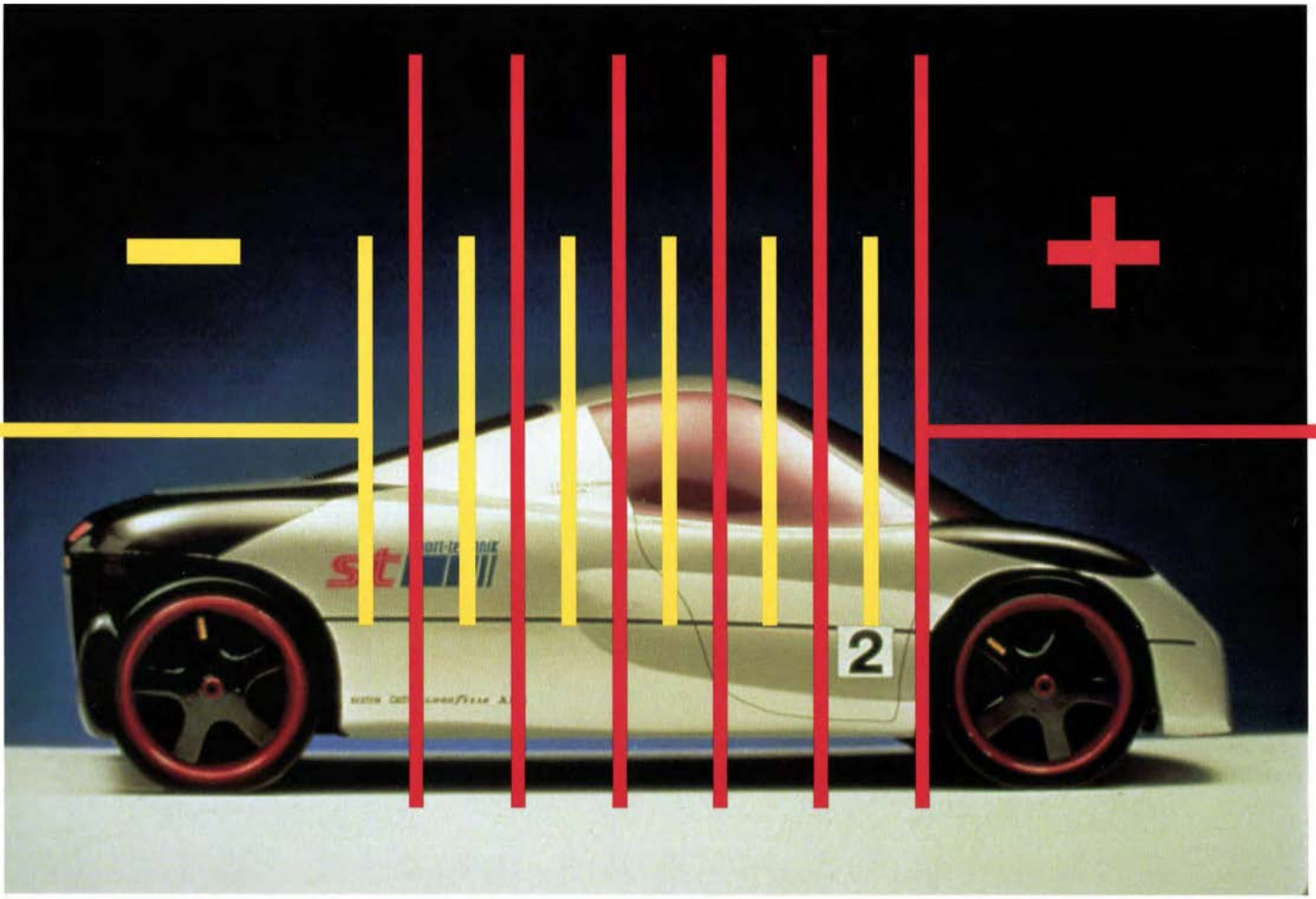

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Cover: The development of advanced batteries that can meet demanding performance and cost goals is still the key to the long-term success of electric vehicles.

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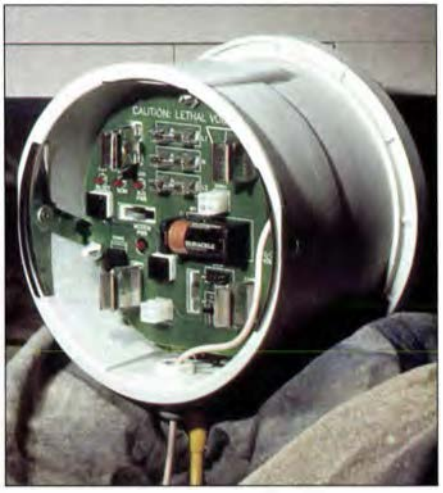

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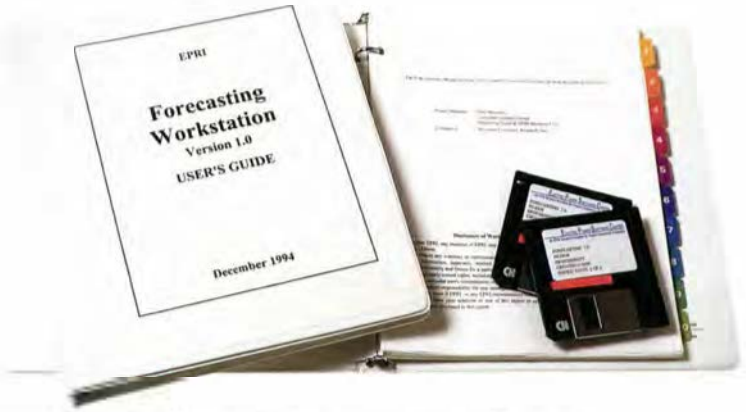
Fault Gas Analyzer

The presence of dissolved gas in the mineral oil dielectric inside transformers can indicate aging, the need for maintenance, or the potential for transformer failure. In the past, electric utilities had to rely on time-consuming, labor-intensive oil sampling and laboratory analysis to determine gas content. But with the introduction of this new low-cost analyzer for transformer fault gases, there is no need to wait. Developed by Micromonitors, Inc., with EPRI funding, this microelectronic device provides real-time measurements of the four key gases that can indicate abnormal conditions in an operating power transformer. Its continuous on-site monitoring provides early warning of conditions that may lead to sudden—possibly even catastrophic—transformer failure.

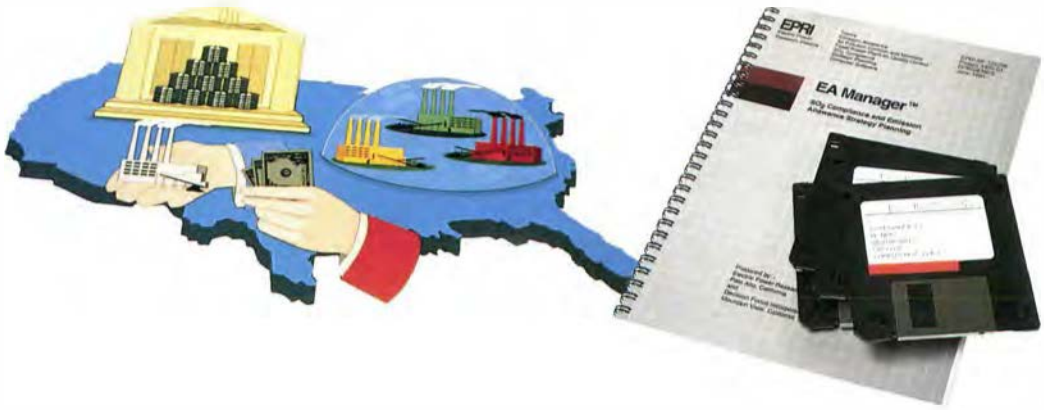
For more information, contact Stan Lindgren, (415) 855-2308. To order, call Micromonitors, Inc., (503) 549-1834.

Forecasting Workstation



This handy software tool provides a Microsoft Windows–based environment that integrates and streamlines the use of EPRI's family of end-use forecasting models (REEPS, COMMEND, INFORM, and HELM). The REEPS, COMMEND, and INFORM programs have become the industry standards for producing end-use consumption forecasts for electricity, natural gas, and other forms of energy in the residential, commercial, and industrial sectors, respectively. HELM performs a variety of forecasting and load-shape analysis functions. From the workstation's main menu, utility analysts can, among other tasks, operate the individual models, generate customized reports (complete with tables and graphs), and compare forecast results for alternative scenarios.

For more information, contact Paul Meagher, (415) 855-2420. To order, call the Electric Power Software Center, (800) 763-3772.



Real-Time Pricing QuickStart Guide

Many electric utilities are introducing fundamental pricing innovations to meet the competitive pressures facing the industry today. This guide (TR-105045) helps utilities deal successfully with the pricing challenge. It provides a basic outline of the major steps required to achieve effective market-based pricing. Although such pricing can take many forms, the guide deals extensively with one approach—real-time pricing (RTP), which involves pricing electricity on a real-time, hourly basis so that prices to participating customers directly reflect market prices (or marginal costs). The guide provides a basis for determining which form of RTP is most beneficial for a utility and its customers in a given situation, and it helps users implement the appropriate form.

For more information, contact Connie Smyser, (415) 855-2396. To order, call the EPRI Distribution Center, (510) 934-4212.

Carbon Tax Report

Concerns about global warming have prompted proposals of various strategies to restrict emissions of carbon dioxide, a greenhouse gas. Carbon taxes are one commonly proposed strategy. This two-volume report (TR-104430) presents the results of a detailed examination of the economic costs of carbon taxes, including where and how the U.S. economy would be impacted. Volume 1 presents an overview of the research and discusses insights developed from an analysis of the results. Volume 2 presents the research results in detail. The report is intended to provide policymakers with methods and information that will enable better-informed decisions about climate policies.

For more information, contact Larry Williams, (415) 855-2695. To order, call the EPRI Distribution Center, (510) 934-4212.

EA Manager 1.5

Designed to help utilities develop and update effective responses to the sulfur dioxide provisions of the 1990 Clean Air Act Amendments, EA Manager lets utility planners analyze a wide range of compliance options, including technological controls, fuel switching, demand-side management, and participation in the emissions allowance (EA) market created by the amendments. The compliance plans developed with this Microsoft Windows–based software program are easy to communicate to internal management and utility regulators. EA Manager incorporates uncertainty regarding future fuel prices, EA prices, and energy demand to provide an understanding of the risks as well as the expected costs of various plans.

For more information, contact Gordon Hester, (415) 855-2696. To order, call the Electric Power Software Center, (800) 763-3772.

Cavitation Treatment for Hazardous Wastes

Fluid cavitation is not generally seen as a utility's friend. The phenomenon occurs when microscopic bubbles form in a liquid as a result of large fluctuations in fluid pressure. These bubbles quickly collapse, instantaneously increasing local pressure and temperature. Repeated collapses near a solid surface can produce mechanical erosion, resulting in damage to pumps, propellers, and other hydraulic equipment.

But the pressure and heat of collapsing bubbles can also destroy dissolved chemicals. In an innovative research effort, EPRI is exploring the use of electrohydraulic cavitation as a simple, convenient process for destroying dilute waterborne hazardous wastes. The technique is being studied for disinfecting drinking water, improving sludge digestion and dewatering, and other industrial applications.

Initial research on the concept, sponsored by EPRI and the U.S. Department of Defense at the California Institute of Technology, demonstrated that pollutants like parathion, carbon tetrachloride, *p*-nitrophenol, and trinitrotoluene could be destroyed by using conventional ultrasound generators over a 2-hour period. However, because the use of such continuous-power ultrasonic equipment requires high power output, research has now shifted to pulsed-power techniques.

The pulsed-power approach, expected to be easily scaled up for industrial use, utilizes the discharge from a capacitor bank to periodically shock contaminated water, creating a 50,000 K plasma bubble and a high-pressure shock wave. The plasma pyrolyzes dissolved pollutants directly while the shock wave creates an intense cavitation leading to hydroxyl radical and supercritical water oxidation. And direct photolysis by the ultraviolet light emitted from the hot plasma destroys pollutants and creates additional hydroxyl radicals.

Pulsed power promises to be more cost-effective than continuous-power methods because energy is delivered throughout a solution and is more fully utilized for chemical destruction. Once initiated, degradation reactions can continue, via chain reactions, to completion; unreacted pollutants diffuse to the electrode area.

Researchers are currently conducting pulsed-power experiments to optimize the destruction of specific pollutants, determine reaction kinetics, and identify intermediate and end products. Although energy density, energy intensity, and properties of the cavitation bubbles can be altered for destroying different pollutants, work to date indicates that relatively little adjustment is needed: for most organics, frequent low-power (5–10-kJ) shocks maximize destruction effectiveness.

■ *For more information, contact Myron Jones, (415) 855-2993.*

Electronic Pasteurization of Meat

Recent incidents of human illness caused by undercooked meat served in fast-food restaurants have raised public concerns about food contamination. Such "farm to fork" concerns over food safety have recently become the focus of a charge by the U.S. Department of Agriculture's Food Safety and Inspection Service that ground-beef products found to contain *E. coli* bacteria should be considered adulterated and unmarketable. The FSIS estimates that human illness caused by food contamination costs the country $8 billion a year in lost productivity. Although the meat-slaughtering industry has tried several techniques to reduce contamination, it has been virtually impossible to render red or white meat microbe-free.

Electronic pasteurization—bombarding the meat with electron beams—may be the most feasible way to destroy remaining pathogens. This technique has been approved for poultry and is expected to be approved for beef shortly. Unlike conventional heat pasteurization, the use of accelerated

electrons does not alter the color, texture, or flavor of food. And unlike irradiating the meat with a nuclear source, such as cobalt 60, electron-beam treatment does not involve negative public perceptions. In addition, electronic pasteurization facilities could be built on either a large or a small scale and would entail simpler licensing procedures than those associated with radioactive materials.

Several questions remain about how to optimize the electronic pasteurization procedure, however, and these are being addressed by researchers at Iowa State University under EPRI sponsorship. In particular, the scientists are considering pretreatment packaging alternatives and are attempting to determine optimal meat temperature and freshness at the time of pasteurization; they are also attempting to determine the maximum shelf life between irradiation and consumption. Other food preservation techniques, such as high-pressure treatment and the use of pulsed electric fields, are also being evaluated. Work is currently under way at Washington State University to examine the effects of these processes on the sensory and shelf-life attributes of food products.

■ *For more information, contact Ammi Amarnath, (415) 855-2548.*

Revolutionizing Power System Analysis

A new type of problem faces utility planners who use massive computer models to keep high-voltage power systems functioning in a stable manner. In the case of heavily loaded systems, qualitative changes in dynamic behavior have been detected that were not predicted by conventional analysis. At best, this discovery means that system operators may have to act overconservatively under certain circumstances; at worst, it could mean that unexpected stresses might spread through a utility network, causing blackouts.

The fundamental mathematical techniques used in today's system stability analyses have changed little in 50 years, although the computer models that apply them have become much larger, more complex, and faster. The basic approach is called linear analysis, which can be visualized as approximating a curved line by using a straight one. If the original line doesn't bend too sharply in the region of interest, this linear approximation works well. But using a straight line may fail badly to represent a precipitous curve. Then, in engineering language, "nonlinear effects" can no longer be ignored.

This is the situation facing power system analysts, since utility networks behave more nonlinearly as they become more heavily loaded. In response, EPRI is sponsoring research on several mathematical techniques that may improve the ability of power system models to predict the effects of nonlinear behavior, including instabilities. One of the most promising approaches has been developed by researchers at Iowa State University, who have found a way to use a nonlinear transformation to convert the complex, nonlinear characteristics of a power system into a form that can accurately be analyzed with existing linear techniques. After this analysis, the results are reconverted so that they again represent the original power system.

"Already we have been able to use this technique to obtain important new information about power systems that the old models could not provide," says project manager Dejan J. Sobajic. "This discovery has the potential to enhance and even revolutionize stability analysis. We anticipate that we will be able to get the first nonlinear software modules into EPRI's power system models within two years."

■ *For more information, contact Dejan J. Sobajic, (415) 855-8537.*

THE STORY IN BRIEF An expert panel has concluded that new high-energy, high-power batteries for electric vehicles could be in commercial production within

THE ROAD AHEAD F

five years. Such batteries are expected to provide realistic vehicle driving ranges exceeding 100 miles and acceleration matching that of all but high-powered internal combustion

automobiles. The panel's assessment of the performance and availability of advanced EV batteries was chartered by the California Air Resources Board to support its reex-

OR EV BATTERIES

by Taylor Moore

amination of a precedent-setting regulation requiring the sale of zero-emission vehicles beginning in 1998. A member of EPRI's senior staff served on the advisory panel.

In 1990, California's air quality regulatory agency announced the nation's first mandate for nonpolluting automobiles, requiring auto manufacturers to offer zero-emission vehicles (ZEVs) as an increasing percentage of total vehicle sales in the state. Specifying an initial quota for ZEVs to account for 2% of vehicle sales in 1998, the mandate was widely hailed as the jump-start that electric vehicles (EVs) needed to break through to large-scale commercial production and to common use by the public.

The California ZEV quota plan was predicated on the commercial availability, by the end of the decade, of battery systems that would enable EVs to offer performance and range capabilities approaching those of conventional vehicles. Within the last few months, partly in response to an expert review and assessment that it chartered of the performance and availability of such advanced batteries, the California Air Resources Board (CARB) has reconsidered the 2% quota for 1998, while announcing its intent to maintain the longer-range goal for ZEVs to account for 10% of vehicle sales by 2003.

CARB's willingness to reconsider the mandate for 1998 has been widely reported as a setback for the future of electric vehicles. In fact, it reflects a considerably more positive outlook for advanced batteries and practical EVs than the headlines suggest.

A cooperative program recently adopted by CARB and major automakers is actually likely to enhance the chances for successful commercial introduction of EVs in the California market. And the mandate is still aimed at achieving, by early in the next decade, emissions reductions similar to those originally planned, as is required of California under federal air quality laws and regulations. What the changes allow are a few additional years for automakers to fully develop and test integrated EVs that offer more-appealing performance and price and that incorporate advanced batteries meeting most or all of the specifications that automakers and others say are necessary to compete with conventional vehicles in the consumer market.

As an alternative to the sales quotas that were to apply in the early years (starting in 1998), CARB and the automakers—Chrysler, Ford, and General Motors (the U.S. Big Three), along with Honda, Mazda, Nissan, and Toyota—agreed that the automakers would offer production-model EVs to the public within the next few years. While there may not be the 20,000 or more EVs rolling in California in 1998 that a 2% sales quota implied, there are likely to be several thousand operating in various niche markets. These early-market EVs will be powered by improved lead-acid batteries and perhaps by nickel-cadmium batteries that, although well short of meeting the performance goals for advanced batteries, will provide better range and power than previously available.

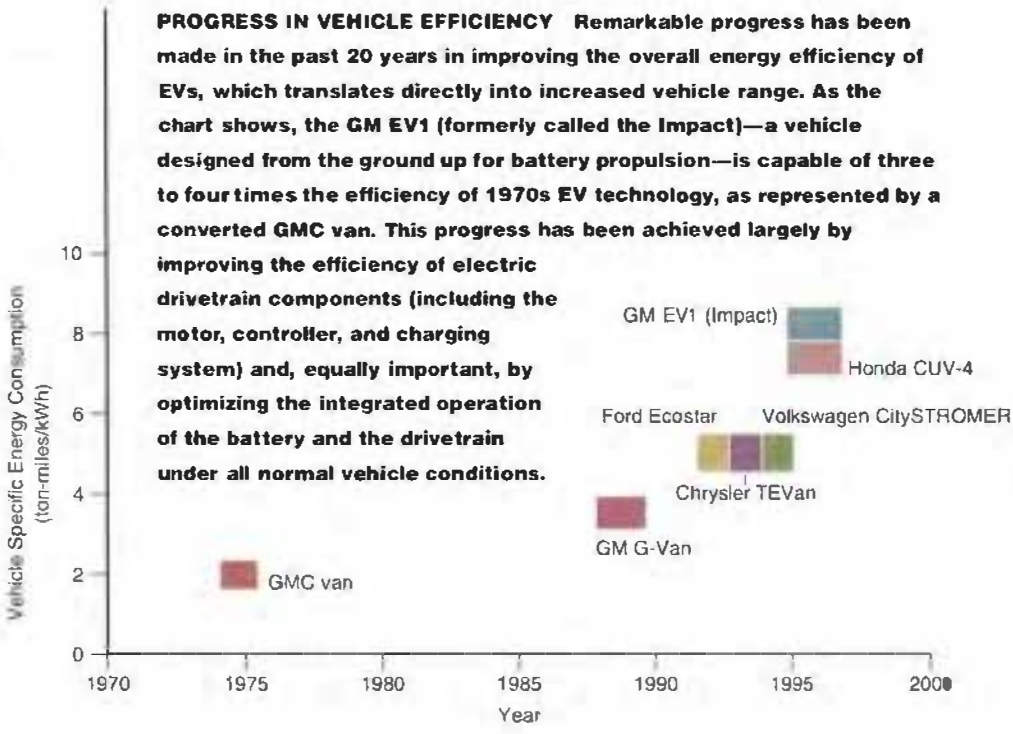
Equally important, CARB's Battery Technical Advisory Panel reported, is that significant numbers of batteries representing several advanced technologies and promising substantially greater performance and cycle life are likely to be available from pilot production lines for in-fleet testing and evaluation by EV developers and manufacturers by 1998. Given the time required for testing, manufacture, and integration into fully engineered EVs, however, such advanced batteries are not likely to be available in commercial vehicles until the 2000–2001 time frame.

A positive outlook, longer term

Says Fritz Kalhammer, cochair of CARB's Battery Technical Advisory Panel, "Overall, our report sends a positive message about the future availability of advanced batteries for EVs." Kalhammer, science and technology coordinator in EPRI's Strategic Development group, is former vice president for strategic research and helped launch the Institute's R&D programs on EVs and advanced batteries nearly 20 years ago.

Kalhammer and the three other members of the CARB-appointed advisory panel (see sidebar, page 15) spent over two months in late 1995 investigating the status of many of the world's leading advanced battery development programs. In this effort, which involved facility visits and written information requests, the panel contacted some 30 organizations in the United States, Europe, and Japan. The programs investigated included most of those supported under the United States Advanced Battery Consortium (USABC), whose sponsoring members include the Big Three U.S. automakers, the U.S. Department of Energy, several utility organizations, and EPRI.

The CARB panel's report, issued as a public document in December 1995, pro-



PROGRESS IN VEHICLE EFFICIENCY **Remarkable progress has been made in the past 20 years in improving the overall energy efficiency of EVs, which translates directly into increased vehicle range. As the chart shows, the GM EV1 (formerly called the Impact)—a vehicle designed from the ground up for battery propulsion—is capable of three to four times the efficiency of 1970s EV technology, as represented by a converted GMC van. This progress has been achieved largely by improving the efficiency of electric drivetrain components (including the motor, controller, and charging system) and, equally important, by optimizing the integrated operation of the battery and the drivetrain under all normal vehicle conditions.**

vides a snapshot of the various advanced EV battery programs and outlines, on the basis of several key measures of performance, the progress each is making toward developing candidate EV battery systems. USABC's detailed technical performance and cost goals for advanced batteries, both for midterm availability (by 1998) and for the long term (by 2004), served as a gauge.

Advanced technologies that have been a focus of development efforts include nickel–metal hydride (Ni-MH), lithium-ion, and lithium-polymer batteries, as well as high-temperature systems like the sodium-sulfur (Na-S) battery and the sodium–nickel chloride, or Zebra, battery. The advisory panel also made a preliminary assessment of batteries using zinc as the negative electrode, which may eventually hold promise for application in EVs.

Status of advanced EV batteries

The CARB advisory panel not only evaluated current and prospective performance measures of the various candidate EV battery systems but also examined the issues likely to govern the commercial availability of these batteries: development schedules, in-vehicle integration and evaluation, and the decisions and investments required for their commercialization.

The key performance parameter indicative of the potential range of an EV with a given battery system is its specific energy, measured in watthours per kilogram. The USABC midterm goal of 80–100 Wh/kg is derived from a 100-mile range criterion, one of several vehicle performance and economic criteria considered the minimum acceptable if EVs are to be embraced by a significant percentage of vehicle users.

The CARB panel found that prototypes of the advanced batteries it investigated have already demonstrated at least the lower bound of the midterm goal for specific energy and that batteries meeting or exceeding the upper bound are likely to be available from pilot plants in quantities of a few hundreds, in some cases beginning this year. None of these batteries, however, is likely to approach the long-term goal for specific energy—200 Wh/kg—anytime soon.

In the case of Ni-MH batteries, European and Japanese developers are achieving 60–70 Wh/kg and expect to reach 70–80 Wh/kg in the near future. GM Ovonic, a joint venture of General Motors and Ovonic Battery Company, expects to produce pilot quantities of a 75–80-Wh/kg Ni-MH battery beginning this year or next; the company hopes to attain 90 Wh/kg by 1998. Developers told the panel that advanced electrode compositions now under investigation might eventually give Ni-MH batteries the high specific energy levels (120–140 Wh/kg) that are projected for lithium-ion and Na-S systems.

The specific energy of lead-acid and nickel-cadmium batteries, despite gains achieved and projected in ongoing development programs, will remain below the midterm USABC goals, the experts concluded. But the improvements being achieved should nonetheless help boost the viability of current limited-range EVs, especially if projected improvements in specific power and cycle life also materialize.

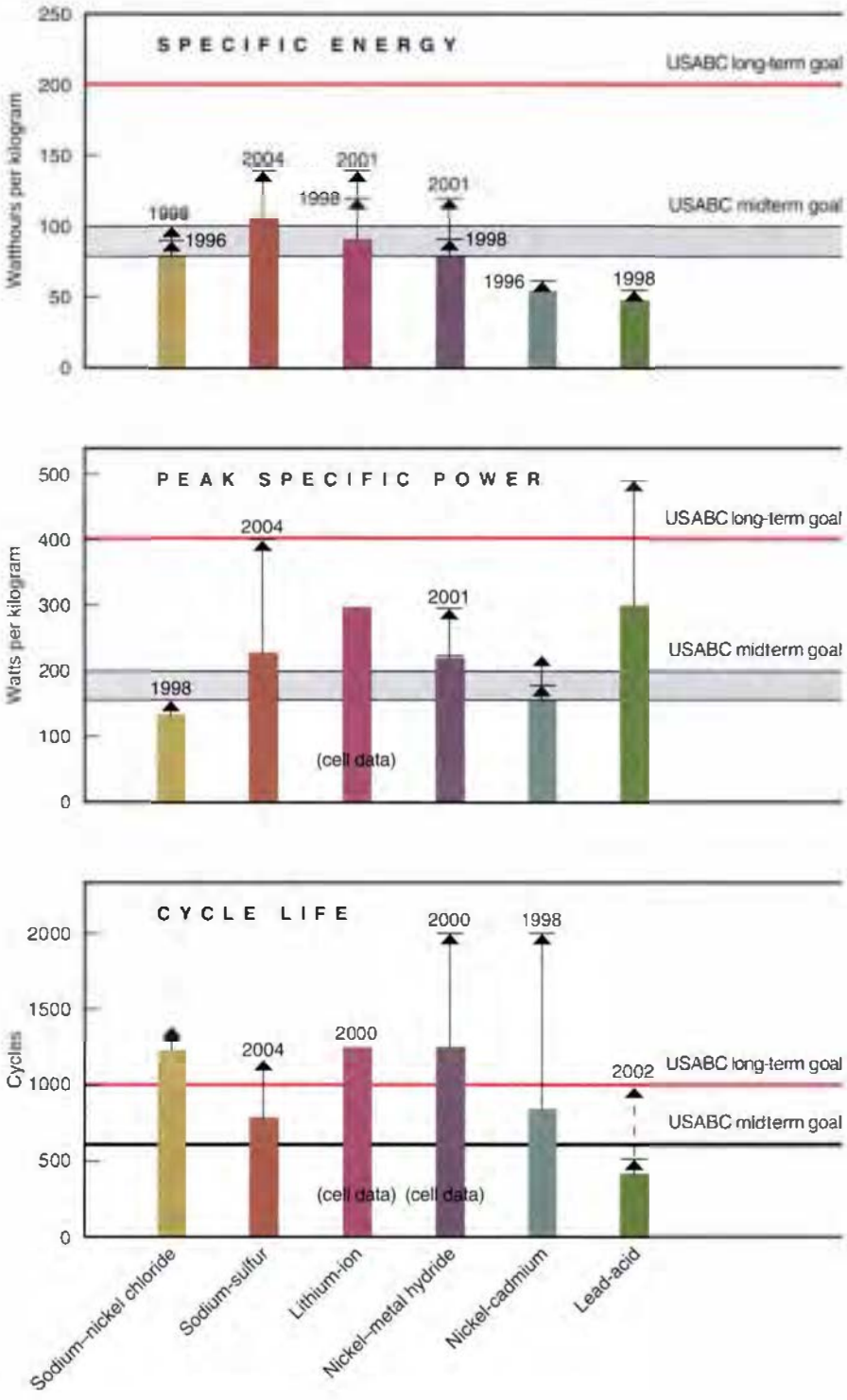
Energy density—the amount of energy stored per unit volume of battery—is another key performance parameter, particularly for converted EVs, because of space constraints and limited design flexibility, but also for EVs designed from the ground up. The midterm USABC goal is 135 Wh/L. The advisory panel found that most of the advanced battery systems under development are projected to approach the long-term goal of 300 Wh/L.

A key battery performance measure that determines potential EV acceleration capability is peak specific power. The outlook for most of the promising advanced battery candidates is also good on this score. All of the likely candidate EV batteries under development, even lead-acid and nickel-cadmium systems, meet or exceed the lower bound of the USABC midterm goal for peak specific power (150 W/kg) that can be sustained for 30 seconds during discharge down to 80% depth of discharge. Most of the candidate technologies are projected to eventually exceed the midterm goal's upper bound of 200 W/kg. Lithium-ion cells—not complete batteries—already exceed this upper bound.

But the advisory panel offered some caveats regarding peak power capability. Several battery types exhibit substantial degradation of peak specific power with increasing cycles of discharging and recharging. Because of this aging effect—caused by irreversible changes in electrodes, electrolytes, and separators as a battery is cycled—the best data for peak specific power are obtained near the end

SONY'S LITHIUM-ION EV BATTERY TECHNOLOGY **Lithium-ion EV batteries have good potential not only for high specific energy but also for long cycle life, since only limited structural changes occur in the electrodes as the battery is cycled. Moreover, lithium-ion batteries can have high reaction rates and high specific power. Several major advanced EV battery development programs in Europe, Japan, and the United States are focused on lithium-ion technology. Sony, the first company to commercialize the technology for application in such consumer products as computer power supplies, has developed cylindrical lithium-ion cells for EVs. These cells look like very large AA batteries, measuring 16 inches long and 2.6 inches in diameter. Each cell provides 100 ampere-hours at 3.6 volts; eight cells are electrically connected in series to form a 2.9-kWh module. As many as 12 such modules in series would be required to power a small passenger EV.**

PERFORMANCE: COMPARING ADVANCED EV BATTERIES **Key EV battery performance parameters evaluated by the CARB advisory panel include specific energy, peak specific power, and cycle life—measures that determine, respectively, an EV's potential range, acceleration, and cost. The panel summarized and integrated information from battery developers on achieved (solid bars) and projected (arrows) performance levels for advanced batteries and for near-term EV battery technologies (lead-acid and nickel-cadmium), which served as a baseline. When available from pilot production, all of the advanced batteries are expected to achieve or exceed the U.S. Advanced Battery Consortium's midterm (1998) goals for these parameters.**



of a battery's useful life. Today's best advanced batteries typically have not yet been cycled to that extent under representative conditions and fully characterized.

Besides providing very high peak specific power for acceleration, batteries must be able to provide high sustained power for high-speed driving. This latter requirement translates into the need for battery thermal control systems capable of removing heat from the battery at a correspondingly high rate. Such systems require specific engineering development as an integral part of EV battery systems.

Long cycle life is a key requirement if advanced EV batteries are to have reasonable life-cycle costs. The USABC midterm goals are for EV batteries to last 600 cycles (or about five years) and to cost no more than $150 per kilowatthour of battery capacity, translating into a life-cycle cost of about 25¢ per kilowatthour of capacity per cycle. The advisory panel called the outlook on cycle life very encouraging, although current estimates are based mostly on cell or module data and must be verified for complete batteries in rigorous testing. Still, developers project an almost universal capability for advanced batteries to exceed the midterm goal—and in the case of sodium–nickel chloride (Zebra), lithium-ion, Ni-MH, and nickel-cadmium batteries, even the long-term cycle life goal of 1000 cycles—within the time frame encompassed by the California ZEV mandate.

One problem is that meaningful cycle life data from accelerated testing do not exist for most advanced battery types because the tests themselves have not yet been developed. Nevertheless, the advisory panel expressed optimism that intelligent electronic control systems for advanced EV batteries will be developed that should enable full-size battery systems to achieve cycle lives approaching the excellent results now being obtained with individual cells and modules.

Availability and cost projections

Key questions posed by CARB were whether and when advanced batteries were likely to become available for the EVs that vehicle manufacturers would be expected to offer under the original terms of

the ZEV mandate. To answer those questions, the advisory panel examined in depth the steps involved as battery developers move new technologies from the laboratory through the prototype and pilot phases to commercial production. To support its analysis, the panel investigated and quantified the typical interactive schedules of battery and EV development. Another key, but longer-term, question was what advanced batteries are expected to cost in commercial production.

As a result of discussions with the developers and manufacturers of batteries and vehicles, the panel concluded that several advanced batteries will become available from pilot production facilities in quantities of several hundreds over the next few years and that improved advanced batteries from commercial production facilities should be available in quantities of tens of thousands per year by the 2000–2001 time frame. This conclusion assumes continuous success along a schedule in which no delays are encountered.

The outlook for the future cost of advanced EV batteries is also encouraging, the panel found. In the limited pilot-scale production phase that is approaching, all of the advanced candidate EV battery technologies under development are expected to cost significantly more than the mid-term USABC goal. However, all of the batteries investigated by the panel are projected to come down in cost substantially, perhaps eventually approaching a cost of $150/kWh in fully mature (so-called learned-out) commercial production on a large scale of about 100,000 batteries per year. The long-term USABC cost goal for advanced batteries is $100/kWh.

In the meantime, most early-production EVs will continue to rely on lead-acid and nickel-cadmium batteries. Several manufacturers are confident that they can get the cost of lead-acid EV batteries under the $150/kWh midterm goal in commercial-scale production of 10,000–40,000 battery packs per year in the next few years. For sealed nickel-cadmium systems, manufacturers are projecting about $300/kWh. However, because of their excellent cycle life (likely to be 1500–2000 cycles), nickel-cadmium batteries should have life-cycle costs comparable to those of lead-acid batteries.

All of the advanced batteries, the advisory panel observed, "can be expected to have excellent cycle life, probably two to three times longer than the best lead-acid batteries and eventually exceeding even USABC long-term goals. Even if the $150/kWh battery cost goal cannot be met in the near term, their longer life should make advanced batteries economically competitive, as their generally attractive life-cycle costs of about 2 0-25¢/kWh-cycle indicate."

General Motors **will begin leasing its EV1, a production version of the two-seater Impact coupe prototype, later this year through Saturn dealerships in Los Angeles, San Diego, Phoenix, and Tucson. GM says that it will also market an electric conversion of the Chevrolet S-10 pickup truck nationwide in 1997 for use in commercial fleets.**

Committing to commercialization

All the advanced battery development programs are proceeding along similar time lines, and most are currently in transition from prototype work to pilot-scale fabrication and fleet vehicle testing. If these advanced batteries are to be available in commercial EVs by 2000–2001, pilot plants must be completed; the quality, performance, and life of batteries from these pilot facilities must be validated; and then com-

mercial production facilities must be built.

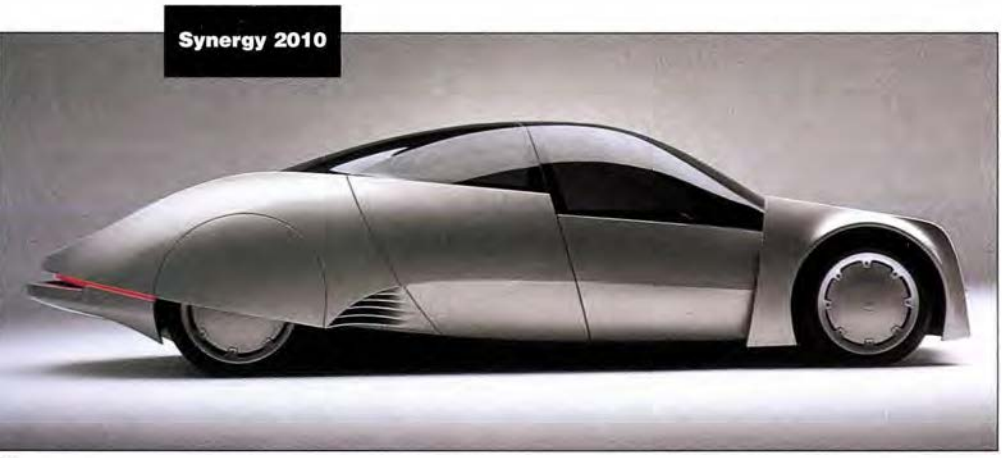
For any particular advanced battery, an all-success schedule requires the timely commitment by a vehicle manufacturer to purchase the battery—and an equally timely commitment by a battery manufacturer to make the typical $50 million to $100 million investment in new plant to produce between 10,000 and 40,000 battery packs a year. The panel found this to be the minimum range of production volume required to realize the economies of scale necessary for acceptable battery costs.

"Our discussions revealed that battery developers and vehicle manufacturers still presently consider such levels of investment commercially very risky because the market for electric vehicles of various types, capabilities, and costs is not well understood," says Kalhammer. "Once you have successfully developed a battery to the prototype stage, as several manufacturers now have, there is much involved in integrating the battery in a vehicle. This process is followed by extensive field testing to derive the final specifications before committing to large-scale commercial production. The levels of investment that are required to carry out these development activities are very large. When you examine what is involved, you can see we are talking about billions of dollars for each fully engineered vehicle and battery system that is commercialized."

Adds Kalhammer, "Before they are willing to make firm order commitments that would support investment in commercial-scale battery production facilities, vehicle manufacturers want a statistically meaningful database from extensive testing of precommercial, pilot production batteries in fleets of prototype EVs, from which they can derive final specifications for commercial batteries. Key drivers for the extensive testing and integration are the safety and reliability of the engineered battery-vehicle system. Moreover, vehicle manufacturers are obviously reluctant to make major investments to produce EVs that they know, initially at least, will have certain limitations in range and performance as well as high cost—factors that make the potential market demand for them very uncertain."

The advisory panel reported a general consensus among battery developers and vehicle manufacturers that without some regulatory pressure like the California ZEV

Ford **has announced plans to offer an electric conversion of its Ranger compact pickup truck, to be marketed primarily to commercial fleets. Ford is also fleet-testing about 100 Ecostar electric vans with a dozen organizations, including several electric utilities and EPRI. In 1995, the automaker displayed a hybrid-electric concept car—Synergy 2010—in which a small engine-generator is used along with batteries to power electric motors in the wheels.**



mandate, there would have been little incentive to push the envelope of EV and battery technologies in the face of the costs, risks, and market uncertainty associated with their development and commercialization. "Battery developers caution that the California program has been the main driving force behind their development efforts for advanced batteries, and that the successful recruitment of investment for the upcoming . . . phases of battery and EV development and commercialization will depend in large part on a continuous and orderly California program," the panel noted.

That concern was evidenced last December, just prior to the completion of the advisory panel's report, when Germany's largest electric utility, RWE Energie, terminated the Na-S battery program of its Silent Power subsidiaries—the only remaining development effort focused on that high-temperature system. Despite the advanced stage of development Silent Power had achieved for this promising technology, RWE officials said that the anticipated California retreat from a 1998 vehicle quota would cause the EV market to develop too slowly to support production of Na-S batteries in volumes sufficient to justify the large investment in automated production required to make them cost-competitive with other advanced batteries.

A better outlook for advanced EVs

Silent Power's exit from the battery development picture notwithstanding, the outlook for the commercial emergence of advanced EV batteries—and vehicles powered by them—early next decade is positive. As the CARB advisory panel noted, "It seems reasonable to expect . . . that at least a few of the 10 or so major programs will move forward at the pace required to make the 2000–2001 dates. This assumes that the perception of a significant future market for electric vehicles continues to be supported, and that ways are found to properly allocate the high costs and substantial risks of the pilot and early commercialization phases of batteries and EVs."

In place of a 2% EV sales quota in 1998, which would have applied to the top seven automobile manufacturers in the California market, CARB is calling for a cooperative, market-based introduction of ZEVs, with a voluntary phase-in of electric vehicles from 1998 to 2000. Carmakers would still be required, however, to meet the previously planned 10% ZEV sales quota by 2003.

Despite the elimination of a looming 1998 quota and the production volumes that it implied, U.S. and other major automakers are moving ahead with plans to commercialize EVs. General Motors has said that later this year it will begin leasing the EV1, a production version of the two-seater Impact coupe it unveiled in 1990—the first EV designed from the ground up—on a limited basis in California and Arizona. GM also plans to introduce an electric conversion of the Chevrolet S-10 pickup truck in 1997. Chrysler showed off its EPIC electric minivan—a production version of the TEVan developed

EPIC minivan

Chrysler **unveiled its EPIC (Electric-Powered Interurban Commuter) minivan in 1995 and said that it expects to market the van primarily to commercial vehicle fleet owners. Developed with Westinghouse Electric, the EPIC is an improved production version of the Chrysler TEVan developed earlier with EPRI support. The EPIC initially will be powered by Horizon advanced lead-acid batteries from Electrosource.**

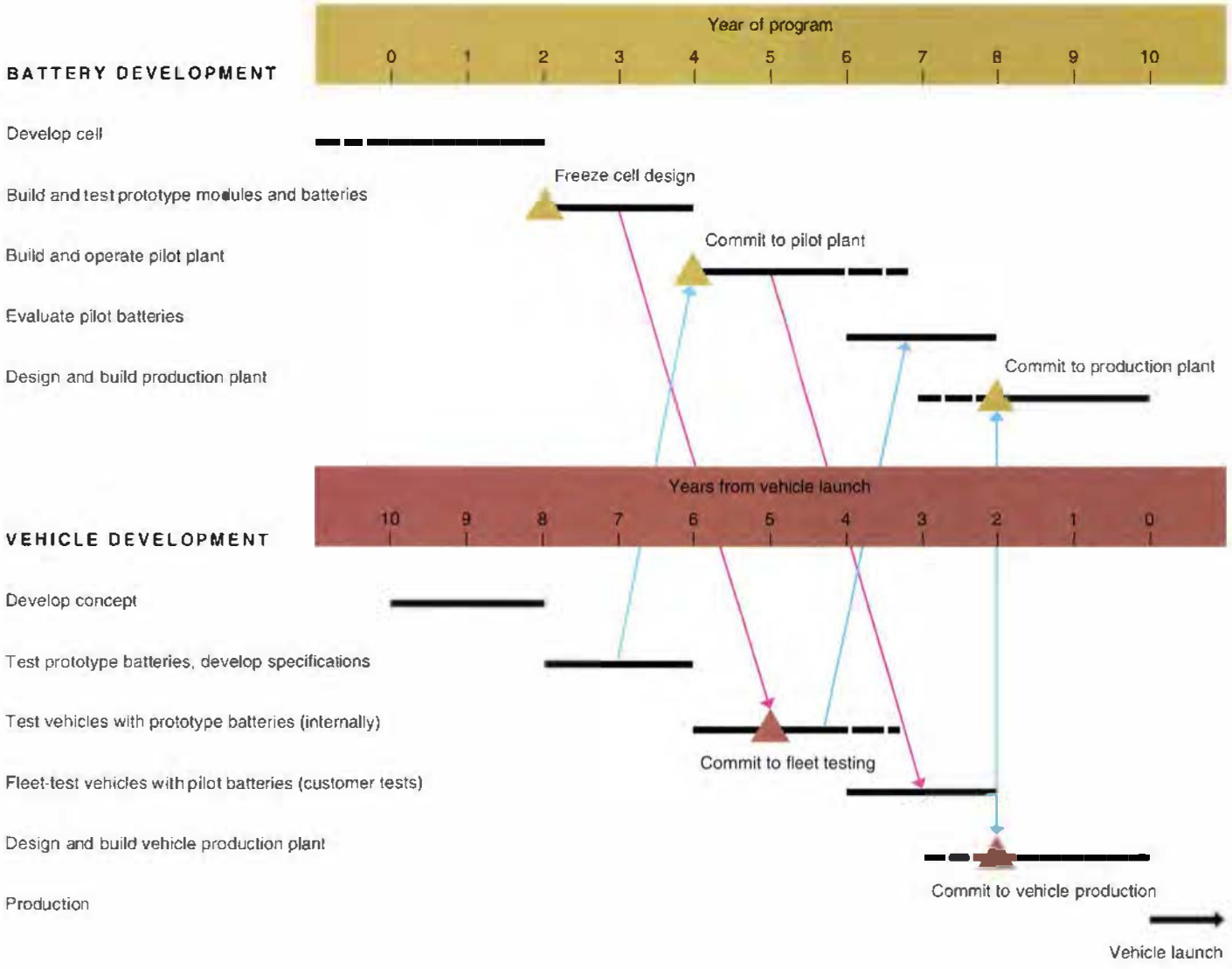
Horizon advanced lead-acid battery pack

EPIC electric drivetrain

with assistance from EPRI—late last year. The EPIC is to be available as a model option for the Dodge Caravan and Plymouth Voyager vans, although Chrysler has not announced a date for commercial launch. Ford, meanwhile, has announced plans to market an electric conversion of its Ranger pickup. All of these vehicles are expected to be equipped initially with lead-acid battery packs. Major Japanese carmakers also have unveiled prototypes of EVs for eventual commercial introduction in California.

Continuing advances in the development and manufacturing scale-up of higher-energy, higher-power, and longer-life integrated EV battery systems in the years ahead will increase the confidence of both vehicle manufacturers and potential users that there is sufficient performance potential—and, in turn, sufficient market demand—to support large-scale commercial development of EVs and battery systems, not just for the California market but in other states as well. Indeed, such advances are imperative if the 10% California vehicle sales goal for ZEVs early next decade is to be met.

In light of the relaxed California mandate and the positive outlook for advanced EV batteries as reported by the CARB advisory panel, EPRI executives say that now is the time to redouble commitments to technology R&D that can ensure the commer-



BATTERY DEVELOPMENT INTERACTS WITH VEHICLE DEVELOPMENT **The CARB Battery Technical Advisory Panel developed a generalized schedule of the key activities involved in developing advanced batteries for EVs. As the battery time line suggests, about 10 years are required from cell development to the achievement of commercial production for a new EV battery technology. Activities to integrate a battery with a vehicle dominate all phases of development, making close coordination of the battery and vehicle development schedules necessary and requiring that vehicle manufacturers be involved at an early stage. Thorough evaluation of batteries from pilot production in fleet vehicle tests is essential to ensure that mature EVs meet consumer expectations for quality, reliability, cost, and safety.**

Continuous roll-to-roll electrode manufacturing line for nickel–metal hydride EV batteries

Ovonic Battery Co.

cial availability of advanced batteries and practical EVs by early next decade. EPRI is continuing to support in-vehicle testing of batteries from pilot-scale production for several advanced battery types and to support the transition from prototype to pilot production for some others.

Through its participation in the USABC on behalf of the electric utility industry, EPRI is actively engaged in collaborative efforts to resolve key questions and to overcome obstacles to the development of the most promising advanced battery systems. Meanwhile, the Horizon advanced lead-acid battery, developed by Electrosource with EPRI support, is expected to be in pilot-scale commercial production next year.

Says Edwin Riddell, manager of EPRI's Electric Transportation Business Unit, "It is now more important than ever to maintain the momentum of the various battery development programs, particularly those supported through the USABC, and to continue to pursue the integration of advanced battery technologies in fully engineered EV designs and prototypes. The outlook for advanced EVs to eventually play a significant role in our transportation systems remains very bright." ■

Background information for this article was provided by Fritz Kalhammer, Strategic Development.

The CARB Battery Technical Advisory Panel

In December 1995, the California Air Resources Board published the report of its Battery Technical Advisory Panel on the status and prospects for advanced EV batteries. The panel was made up of four experts who have had long professional involvement with battery and vehicle technologies.

Fritz Kalhammer, cochair, is coordinator for science and technology in EPRI's Strategic Development group. Before assuming this part-time position, he was vice president for the Institute's strategic R&D. Kalhammer, who joined EPRI in 1973, established the Institute's R&D programs for energy storage, fuel cells, and electric vehicles and helped organize its end-use R&D. From 1979 to 1988, he guided energy management and utilization research, serving as division director and then as vice president. Before joining EPRI, Kalhammer worked for 12 years at Stanford Research Institute (now SRI International), ultimately as manager of the electrochemistry program. Earlier he worked for Philco Corporation as a solid-state physicist and for Hoechst in Germany as a research chemist. Kalhammer received BS and MS degrees in physics and a PhD degree in physical chemistry from the University of Munich.

Carl Moyer, cochair, is chief scientist of Acurex Environmental Corporation, Mountain View, California. With more than 25 years of technical experience in fuels, combustion, emissions, and air quality impacts, Moyer has worked with various groups—mostly with the major California regulatory agencies but also with the U.S. Environmental Protection Agency, other federal agencies, research organizations, and oil companies. Moyer's work has covered the performance and cost of low-emission vehicle and clean-fuel technologies; the supply and cost of electric, methanol, and natural gas vehicles; and the design of technical and regulatory emissions control programs. Moyer received a BS degree in engineering science and MS and PhD degrees in mechanical engineering from Stanford University.

Akiya Kozawa was a corporate research fellow of Union Carbide Corporation when he retired in 1989 after 25 years with the company. Earlier he was an assistant professor of chemistry at Western Reserve University, and still earlier, an assistant professor, lecturer, and researcher at Nagoya University in Japan. The author of some 100 technical and professional publications, Kozawa was for several years the editor of the Electrochemical Society of Japan's journal, *Denki Kagaku*, and a related newsletter.

Boone Owens, a recognized scientist in battery technology and electrochemistry, is a private consultant and also an adjunct professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. He is a former battery R&D executive at Medtronic, Gould, and Atomics International. His specific areas of expertise include lithium, solid-state, and polymer electrolyte batteries. Owens received a BA degree in chemistry from Whittier College and a PhD degree in physical chemistry from Iowa State University. □

Mowing Down P

by Leslie Lamarre

ollution

THE STORY IN BRIEF New state and federal air quality regulations are cracking down on the gasoline-powered lawn mower, limiting air pollutants emitted by this previously unregulated machine. A recent study sponsored by EPRI, the Environmental Protection Agency, the Edison Electric Institute, and 18 electric utilities undertook the first-ever national sampling of emissions from gasoline mowers in use and found that the mowers are even dirtier than previously believed. The results showed that the emissions associated with cordless electric mowers (i.e., emissions from plants generating the power to charge them) are dramatically lower than those from gasoline mowers—in some cases, thousands of times lower. What's more, consumers who swapped their gasoline mowers for cordless electric mowers through the study were very pleased with the change, finding the electrics comparable in performance and superior in convenience. Manufacturers are gearing up for what many anticipate will be a thriving market for cordless electric mowers, and electric utilities are stepping up their support for the technology.

The roar of the lawn mower engine has long heralded the arrival of summer. It's a sound associated with backyard barbecues, chirping birds, and the scent of fresh-cut grass. But such pleasant associations are starting to fade as government agencies begin to clamp down on the gasoline-powered machines that have groomed the great American lawn for nearly 100 years.

For the first time ever, national regulations have been adopted to curb pollutants emitted by lawn mowers and other equipment with gasoline-powered engines under 25 horsepower. Effective for 1997 models, the regulations promulgated by the Environmental Protection Agency limit emissions of hydrocarbons, carbon monoxide, and nitrogen oxides from "utility engines"—a category that includes a variety of lawn and garden equipment as well as "general utility equipment" such as compressors, generators, and pumps.

"People think that because these engines are so small, they must not pollute so much," says Gay MacGregor, a division director at the EPA's National Vehicle and Fuel Emissions Laboratory in Ann Arbor, Michigan. "But this is a misconception. Whereas automobiles have been regulated for 20 years, lawn mowers and other lawn and garden equipment have remained unregulated and now represent a significant source of air pollution." Indeed, the California Air Resources Board, which laid the groundwork for the federal regulations with a similar set of standards in 1995, called garden equipment "the single largest unregulated source of carbon monoxide and hydrocarbon emissions."

The EPA has known for some time that lawn mowers are big polluters. But the extent to which they contribute to poor air quality was not precisely known until the completion of a recent study in which the EPA measured the air pollutants emitted by residential lawn mowers actually in use. The study, called the CLEANER (Cordless Electric Advancing Noise & Emissions Reductions) LawnCare project, compared the emissions from these gasoline-powered machines with the air pollutants associated with electric lawn mowers—namely, exhaust from the stacks of electric power plants. Funded jointly by the EPA, EPRI, the Edison Electric Institute (EEI), and 18 electric power companies, the CLEANER LawnCare project relied on the participating electric utilities to randomly select consumers to trade in their used but operating gasoline-powered lawn mowers for new cordless electric mowers. In all, some 1700 mowers were traded in, representing a variety of mower types and ages. The EPA selected 60 representative machines to test at its emissions laboratory in Ann Arbor.

The study turned up some interesting results, which will soon be released in an EPRI report, *The Environmental and Energy Benefits of Cordless Electric Lawn Mowers* (expected to be out by mid-1996). Compared with cordless electric mowers (and the power plant emissions they involve), the gasoline mowers typically used across the country emit 8 times more nitrogen oxides, 3300 times more hydrocarbons, 5000 times more carbon monoxide, and more than twice the carbon dioxide per hour of operation. According to Mark Mills, president of Mills McCarthy & Associates, Inc., the energy technology research consulting firm that conducted the CLEANER LawnCare study, if just 20% of the U.S. homeowners with gasoline mowers switched to cordless electric mowers, there would be annual emissions reductions of 10,800 tons of hydrocarbons, 340 tons of nitrogen oxides, 84,000 tons of carbon monoxide, and 70,000 tons of carbon dioxide.

"This was the first national sampling of emissions from lawn mowers actually in use," says the EPA's MacGregor, noting that previous assumptions about lawn mower emissions were based on new mowers, which are considerably cleaner than used ones. "We were surprised by how dirty the used mowers are compared to new ones. On average, they emit twice the hydrocarbons released by new mowers."

Gary Purcell, EPRI's manager for the CLEANER LawnCare project, notes that

Emissions per Hour of Operation (grams per hour for a single mower)

	HC	NO_x	CO	CO_2
EPA 1997 standard	15.75	5.25	612.5	—
In-use gasoline mower	59	2	457	963
Cordless electric mower	0.018	0.25	0.09	450

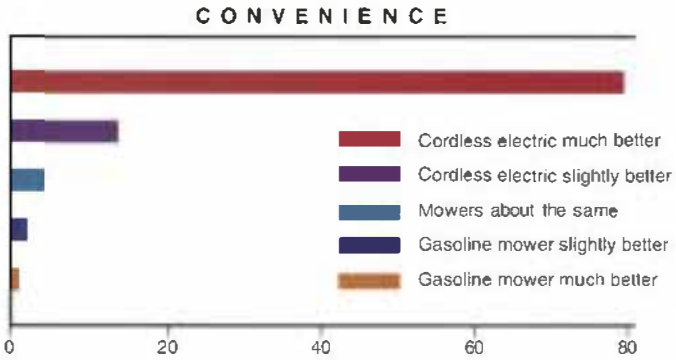
THE ELECTRIC ADVANTAGE **Emissions from gasoline mowers far exceed those associated with cordless electric mowers, as the figures in this table indicate. All the cordless mower emissions are scant fractions of the limits the EPA has set for gasoline-powered machines for 1997, while gasoline mower emissions exceed the limit for hydrocarbons. The gasoline mower emissions are based on the results of a recent study involving the testing of mowers that consumers had actually been using. Since the electric mowers produce no emissions during operation, the cordless electric numbers are based on data for national average power plant emissions.**

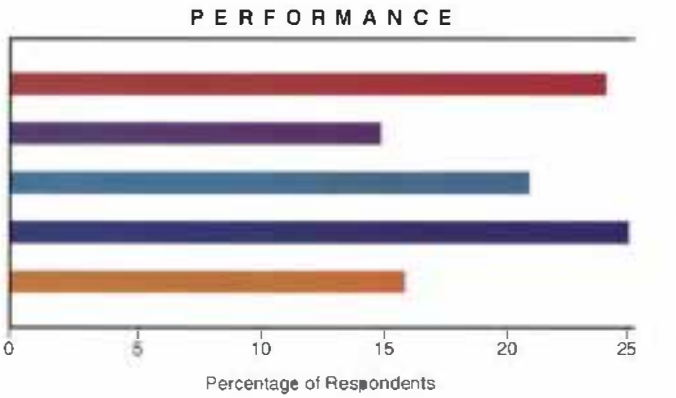
THUMBS UP FOR CORDLESS MOWERS

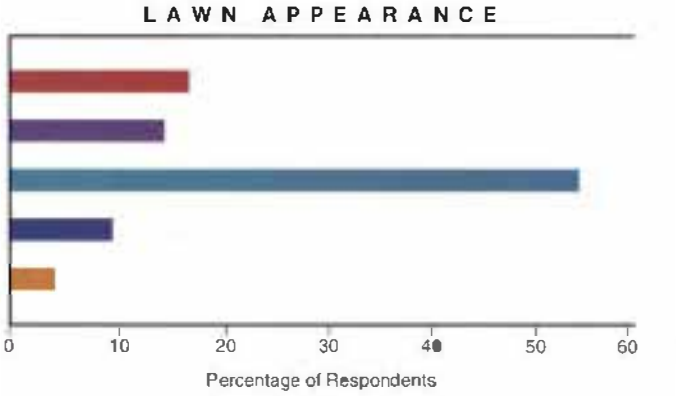
Of the CLEANER LawnCare project participants who responded to a customer satisfaction survey, 90% said they would recommend that a friend or relative buy a cordless electric mower. And when asked to compare the cordless mower with the gasoline mowers they traded in, survey respondents gave the electric machine high marks. Here's how survey respondents ranked the mowers in four of the survey categories.

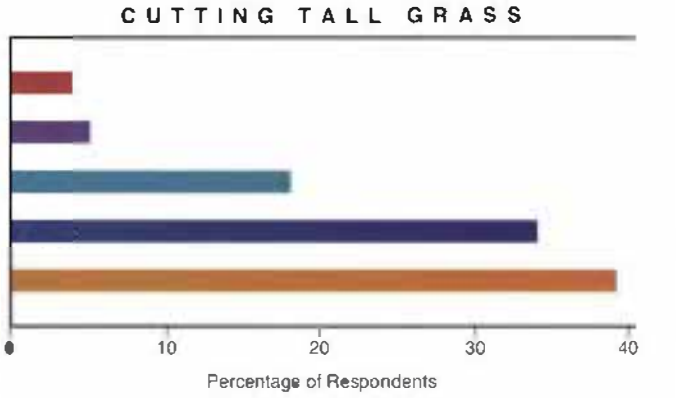
The Black & Decker cordless mower stands apart from the gasoline mowers collected through the CLEANER LawnCare project.

Utility customers receive instructions on operating their new cordless electric mower.









the study's results are actually quite conservative, since they include only emissions coming from the tailpipes of gasoline mowers—one of five types of emissions associated with these mowers. The study did not account for emissions resulting from gasoline spills during refueling, for example. (The EPA estimates that 17 million gallons of fuel are spilled each year in refueling lawn and garden equipment—more than the amount of oil spilled by the *Exxon Valdez* in 1989.) Nor did the study consider emissions from leaky gaskets and other engine parts, postoperative emissions that are released after a hot engine is turned off, and the hydrocarbons continuously emitted by gas tanks through evaporation. According to estimates from the California Air Resources Board, these four types of emissions combined may actually exceed the tailpipe emissions from gasoline mowers. By contrast, power plant exhaust is the only source of pollutants associated with electric mowers. (The data on emissions for the cordless mowers in the study were based on national average emissions from power plants.)

Consumer response

The CLEANER LawnCare project was initiated not just to collect hard data on lawn mower emissions but also to determine the response of consumers to cordless electric lawn mowers. The cordless mower selected for this study was Black & Decker's CM500—the only thoroughly field-tested cordless mower on the market at the time the study was initiated. This side-discharge mower has a 1.4-cubic-foot grass catcher and an 18-inch cutting width and can perform up to an hour's worth of cutting on a full charge. Fully charging the mower, which can be accomplished by means of a standard wall outlet, takes 20 hours, although the battery attains 75% of its charge in 3 hours.

The participating consumers traded in all kinds of gasoline-powered lawn mowers for the study, including models put out by Sears, Toro, and Honda. The mowers ranged in age from 1 to 25 years. The 1700 participants were given 30 days to try out their cordless mowers. If they weren't satisfied, they were allowed to get their gasoline mowers back. According to the 10 utilities that responded to a survey about cordless mower returns, an average of 3% of the customers involved in the exchange wanted their gasoline mowers back. Those consumers cited various reasons. For example, some were disappointed in the electric mower's lack of specific features (such as mulching), some were concerned that the mower lacked enough power for tough jobs, and some complained that the machine cut unevenly. (Those concerns have since been addressed by Black & Decker and other cordless mower manufacturers.)

The project sponsors developed a 100-question survey to find out exactly what participating consumers thought about their cordless mowers after using them throughout the 1993 cutting season. The 78% that responded were very positive, with 90% saying they would recommend that a friend or relative buy a cordless mower.

Asked to compare 14 aspects of the cordless electric mowers and the gasoline mowers they traded in, participants said that the cordless mower was much better in the categories of convenience, user-friendliness, environmental friendliness, maintenance, safety, and use in residential areas (i.e., noise). The gasoline mowers were strongly preferred for cutting weeds, wet grass, and tall grass. In the category of mower performance, consumer opinions were just about evenly split between the two types of mowers, with gasoline mowers having a slight edge.

"As this study confirms, electric lawn mowers are attractive for a number of reasons," says Purcell. "Not only are they clean, releasing no direct pollutants, but they are relatively quiet." Users say that electric mowers are about as loud as vacuum cleaners—a volume low enough to hear the grass being cut. Because the newer models on the market, such as the Black & Decker machine used in this study, are cordless, they overcome the problem of being tethered—a major drawback of the earlier, corded generation of electric mowers. Other advantages are that owners don't have to obtain and store gasoline or maintain the mower by changing oil and spark plugs. And operation of electric mowers is cheap: a single lawn cutting uses less electricity than it takes to burn a 60-watt lightbulb for a day. According to EEI, a year's worth of mowing costs less than $4.

Since the study was initiated, manufacturers have introduced more-powerful cordless mowers. And soon there will be models with even more power. Electrosource, an innovator in batteries for electric vehicles, is modifying its advanced lead acid battery for use in cordless lawn mowers. The new battery, which incorporates lightweight materials, is expected to put cordless mowers on a par with the most powerful gasoline mowers for the first time—overcoming problems with long grass, weeds, and wet grass. Mowers with the new battery will be available late this year.

The survey of cordless mower users offers some valuable insights for mower manufacturers, since it shows consumers' perspectives on the machine's weaknesses and their preferences for additional features. Asked to rank the mower's single greatest weakness, 29% said power, 23% specified blade size (the mower's cutting width was 2 inches smaller than that of nearly all the gasoline mowers traded in), 20% said the battery (referring to the 1-hour operating time), 12% cited uneven mowing, and 10% said the grass catcher (consumers generally prefer rear-mounted to side-mounted bags); 6% reported no weakness. When asked about specific features that would be the most desirable to add, 27% specified a wider-cutting blade, 25% wanted mulching, 18% opted for self-propulsion, 17% asked for a faster charge, and 13% wanted a different handle.

A growing market

Manufacturers have already begun to address these concerns. For instance, cordless units on the market today have advanced features like self-propulsion, mulching, and interchangeable battery packs. "We see it as an important if not huge market," says Frank Coots, director of public relations for Ryobi, which introduced its first electric mowers—both corded and cordless models—just three years ago. "Ryobi operates under a set of six internal values, and one of them is environmental friendliness. We

try to introduce products that reflect these values. The electric mower is one example." The motivation was also external, Coots says. "We saw a market for battery-powered equipment that we believe is growing, particularly as California and some other areas are moving to limit pollution from gasoline-powered equipment."

The California regulations impose emissions limits in two tiers, with the second tier of more-stringent regulations coming in 1999. The EPA is currently working on a proposal for a second, more-stringent tier of regulations, but at this time it is uncertain when such regulations would be imposed. The state and federal standards both require that manufacturers who want to sell such equipment have the engines tested to ensure that they meet the limits. Manufacturers expect the first-tier state and federal regulations to require only mi-

A GROWING MARKET The number of cordless mowers on the market is proliferating. Just three years ago, when the CLEANER LawnCare project began, only two companies sold cordless mowers. Today at least half a dozen companies have introduced cordless mowers, and the number is rapidly increasing. Models out for this cutting season offer advanced features like mulching and self-propulsion. Here is just a small sample of the mowers available this year.

MTD's Eliminator

Ryobi's BMM2400

Ryobi's BMP2418

Black & Decker's CMM625

Black & Decker's CMM1000

Husqvarna's 43RC

Photos: David Morin

USER-FRIENDLY Cordless lawn mowers with even more convenience features are coming on the market. For example, this model from Briggs & Stratton comes with a spare battery that users can charge through a standard 120-volt outlet. When the battery in the mower is exhausted, it can easily be lifted out and replaced with the freshly charged battery.

nor adjustments in the fuel mixture and the ignition and valve timing of gasoline mowers. But California's second tier will likely require significant modifications, such as the addition of catalytic converters and other pollution control devices like those used in cars. Such modifications are expected to significantly increase the price of gasoline mowers. At the same time, the price of electric mowers is coming down. For example, the Black & Decker unit tested in the CLEANER LawnCare study cost $450 at the time the project was initiated in 1993. Now, three years later, the same unit costs $250, making it competitive with comparable gasoline mowers available today.

Currently, according to Mills McCarthy & Associates, 4 million mowers are sold in the United States each year, 10% of which are electric (with cordless mowers representing about 10% of this fraction). But many observers anticipate important changes in this market. Indeed, what started out more than 20 years ago as a sideline for makers of electric power tools, such as Black & Decker, is now being pursued by makers of gasoline-powered equipment, such as Briggs & Stratton. The largest producer of air-cooled gasoline engines for outdoor power equipment in the world, Briggs & Stratton is introducing its first battery-powered mower this spring. It's a convertible mulcher that comes with two removable battery packs, enabling users to charge one pack while using the other. As is the case with the engines it makes for gasoline-powered mowers, Briggs & Stratton does not sell the cordless mowers directly to consumers but supplies customized versions to various lawn mower manufacturers.

Husqvarna, another company with a tradition in gasoline-powered equipment, introduced its first battery-powered mower in 1994. Called the 43RC, this cordless mulching mower and a battery-powered trimmer are the company's only battery-powered equipment. But that is likely to change, says Bob Pisano, a spokesman for the 304-year-old Swedish company.

"There's no question about it," says Pisano. "We believe that battery-powered mowers are going to continue to grow in market share—primarily because of environmental concerns." He notes that four years ago, he knew of only one company that was making cordless mowers; now there are at least six. "We see the writing on the wall, and we believe battery-powered equipment is going to continue to grow in popularity, especially as baby boomers get older. Electrically powered equipment is easier to start, is quieter, costs less to operate, and has a lot of other advantages over gasoline." Pisano says that his company hopes to expand into other types of battery-powered equipment.

"Electric mowers have always been a small niche in the overall mower market," says Susan Amey, product manager for Black & Decker's outdoor products. "But we really feel that with all the attention being placed on how much gas mowers pollute, the market is on the verge of exploding." According to Amey, electric mowers (both corded and cordless) represent 52% of the European mower market. Noise regulations and the fact that European consumers have smaller yards are two reasons for the larger market overseas. Also, when surveyed about lawn mowers, Europeans specified convenience as their top concern, while Americans said power was their main interest.

Utility involvement

Mark Mills says that electric utility efforts in the CLEANER LawnCare project have helped jump-start the market for cordless mowers. Utility advertisements and other forms of publicity about the mower trade-in piqued the interest of hundreds of thousands of consumers and retailers. And the many satisfied users of the cordless mowers are spreading the word to relatives and friends.

The study resulted in direct utility benefits as well. The survey conducted after the project shows that 78% of the respondents had a higher opinion of their electric utility because of the company's participation in the project; 48% of all the respondents said that their opinion was "much" higher. "We

used the study not only as a research project but as a public relations tool," notes Mike Newcombe, coordinator for new electrotechnologies and environmental issues at Oklahoma Gas and Electric Company. Newcombe says that his utility publicized the project through a chain of grocery stores with an outlet in just about every district of OG&E's service territory. Utility organizers set up a booth with a sample mower at each store and signed up shoppers as they came and went. In all, 500,000 entries were collected, of which the utility drew 100 for the lawn mower swap.

Other utilities opted to ward off such an overwhelming response by asking for a monetary contribution in addition to the exchange of a gasoline mower. Among them was Centerior Energy Corporation, which asked for $100 in addition to the used mower. Still, the utility got 32,000 consumers who wanted to participate, says Centerior's Luann Sharp, a manager for public affairs. "I expected a good response, but I did not expect the overwhelming response we received," she says. "It seemed almost as if it was a pent-up market, waiting to be filled." Sharp, who was the project manager for Centerior, spoke with many of the customers during the recruiting period and during the utility's follow-up survey. "A lot of people I talked with indicated that they liked the idea of doing something good for the environment," she says. Others had more-specific motivations for participating. One person with rheumatoid arthritis was unable to pull-start the gasoline mower. A participant with asthma reported that the absence of fumes from the electric mower made grass cutting tolerable.

Potomac Electric Power Company received such a favorable response to the lawn mower swap that it followed up with another program offering rebates for the purchase of cordless mowers. Steve Sunderhauf of PEPCO's market planning and policy group reports that 190 consumers who bought cordless mowers in the spring and summer of last year received $70 rebates. Sponsoring the program with PEPCO were Black & Decker, Ryobi, the state of Maryland's Department of Environment, and two county environmental agencies.

Electric utilities are also using other avenues to nurture the fledgling market for cordless mowers. Some are pursuing R&D projects to bolster the technology. For instance, 11 utilities have joined EPRI's Nonroad Electric Vehicle Applications Consortium, which was established to support research on all kinds of nonroad EV projects, from lawn mowers to lift trucks. The consortium is still open to new members. Other utilities are involved in efforts to actively market such technologies.

A launchpad

Mills believes that the cordless electric mower is a great launchpad for other electrotechnologies. And according to research conducted for the CLEANER LawnCare project, consumers are ready. After the project, 83% of participants responding to the sponsors' survey said they were interested in other electrotechnologies, such as grills, heat pumps, indoor air cleaners, and automobiles. Asked if they would be interested in using other cordless electric lawn and garden care products, 81% of the survey respondents said yes.

"The electric lawn mower is the utility marketer's dream—an easily understandable means of relaying the message that using more electricity will decrease air pollution," says Mills. "You can talk demand-side management rhetoric until you drop, and consumers may still walk away scratching their heads. But an electric mower—this is something they know and understand."

Just as important as the environmental benefits and the convenience of electric mowers are the technology's availability and affordability. As Mills points out, getting U.S. consumers to use electric lawn mowers is feasible at this time. And, he says, the environmental benefits of replacing half the residential walk-behind gasoline mowers in the country (i.e., replacing about 1.3 million mowers) with electric mowers is the air quality equivalent of eliminating the hydrocarbon exhaust of more than 2 million cars—even accounting for the emissions from power plant stacks. The switch would also eliminate 55,000 cars' worth of nitrogen oxide emissions, 1.3 million cars' worth of carbon monoxide, and 65,000 cars' worth of carbon dioxide.

Certainly the sound of the mowing season would be lowered by more than a few decibels if the hum of millions of cordless mowers were to replace the roar of their gasoline counterparts. And as Purcell of EPRI observes, "Consumers could rightly associate that sound with good things." ■

Background information for this article was provided by Gary Purcell of the Customer Systems Group's Electric Transportation Business Unit.

THE STORY IN BRIEF ***A new electronic data recording system will soon be available that can recognize and track the digital signatures of individual appliances and provide utilities and their customers with detailed data on electricity use. Although the system's initial commercial release for utility use is targeted for the residential customer market, developers are working on a version for application at commercial and industrial customer sites that may eventually enable remote diagnostics for major loads like motors. Meanwhile, the system is expected to be popular with utilities and researchers for end-use load research and other studies that now require entering customer premises and hardwiring appliances to a computer.***

by Taylor Moore

Load Monitoring

Using pattern recognition techniques, a small electronic monitor now approaching commercial availability will allow utilities to identify and track the power demand and electricity use of specific appliances and loads, yet spare customers the intrusion and inconvenience that this task now entails. Developed with EPRI support, the device can be installed on a customer's outdoor service meter to automatically and continuously record and transmit digital data that can be analyzed with special software to provide detailed information on electricity use.

Utility managers and researchers who are familiar with the device—known as the Non-Intrusive Appliance Load Monitoring System, or NIALMS—say that it should be a boon to utilities both for end-use load research and for verification of the results of energy demand-side management (DSM) measures. Such efforts now typically involve obtaining the permission and assistance of customers to enter their premises and wire an assortment of monitors for individual appliances to a computer. And developers envision more-promising commercial prospects for NIALMS down the road as a customer-level electronic device that will permit more-sophisticated utility services: disaggregated billing for major appliances, time-of-use billing, resolution of billing disputes, and even remote diagnostics for such commercial loads as motors. Eventually, experts believe, the technology could be integrated with a customer control interface that would use the bidirectional communications already possible over utility lines to realize many of the capabilities envisioned for the information superhighway.

NIALMS, which is scheduled to be introduced onto the residential utility customer market in June, was developed by Telog Instruments, a Victor, New York, manufacturer of microprocessor-based data acquisition and communication systems for power quality, water, and industrial monitoring markets. In 1992, Telog joined and intensified an EPRI-led development program that had begun in 1984, soon after government-funded researchers at the Massachusetts Institute of Technology (MIT) had discovered the feasibility of identifying the power profiles of individual appliances in scatter plots of step changes in real and reactive power (watt and VAR measurements). Such measurements can be made and used for tracking many individual appliances from a single point on a circuit.

Telog is commercializing NIALMS with internal funding and with support from EPRI, the Empire State Electric Energy Research Corporation (ESEERCO), the New York State Energy Research and Development Authority, Consolidated Edison Company of New York, and Rochester Gas and Electric Corporation (RG&E).

In cooperation with Telog under EPRI-led tailored collaboration research, seven electric utilities are now field-testing NIALMS at up to six customer sites each. Hardwired appliance monitoring is also being conducted at the sites to provide comparison data for documenting the accuracy of NIALMS. Through these field tests, the utilities are providing Telog with critical user and customer feedback that is helping to refine the precision and reliability of NIALMS as well as to enlarge the database of recognizable appliance power profiles. EPRI is also sponsoring advanced technology research at MIT and elsewhere to develop systems for use at commercial and industrial customer sites and to develop improvements that will help in identifying harder-to-track multistate appliances, like dishwashers.

"Of all the products I've seen come from EPRI research that involve the customer side of the meter, I believe this one holds the most promise to be commercially successful," says Bernie Woller, director of facilities and special projects at Buckeye Power, a generation and transmission company for 27 rural electric cooperatives in Ohio and one of the utilities that is field-testing the NIALMS residential system. "We are excited about NIALMS and are looking forward to it coming onto the market," adds Woller. Buckeye Power promotes the use of such peak-shaving appliances as heat pumps by its member cooperatives'

Enters the Digital Age

270,000 residential consumers and could use NIALMS data to help determine consumer load curves and to develop rates and programs to minimize peak loads.

Prototypes confirmed feasibility

According to Laurence Carmichael, who manages the NIALMS work and other customer interface and controls R&D in EPRI's Information Systems & Telecommunications Business Unit, early prototypes of a NIALMS predecessor confirmed the feasibility of such a monitoring system. In field tests at five houses in RG&E's service area and five in New England Power Company's service area in the late 1980s, the prototypes measured the electricity use of large residential loads with an average accuracy of 90-95%. But the tests highlighted the need for further development, particularly of improved algorithms for identifying multistate appliances and of ways to reduce the system's installed cost to within an economically attractive range.

Once it is programmed and installed at a residential meter, NIALMS calculates and stores time- and date-stamped readings of stepwise changes in total power use above a set threshold as household appliances turn on and off. The unit also calculates and stores watthour and VAR-hour data for each recording interval. Data stored in its memory are periodically transmitted via internal modem over a standard telephone line to a Telog NIALMS master station located at the utility. The data can also be retrieved with a handheld data recorder or a portable computer. The system architecture and hardware design of NIALMS will also enable implementation with other communications networks, such as radio-based and hybrid systems.

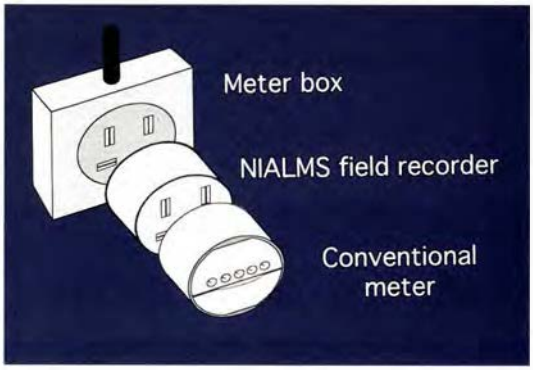
The NIALMS master station software runs on a 486 or higher IBM-compatible PC with the Windows NT 3.5 operating system. It plots edge transition scatter data on a watt-VAR graph. Data from a single appliance tend to form clusters on such a graph, and a pattern recognition algorithm is used to compare these clusters with appliance signatures in a software library. A positive identification is made when a cluster matches a stored signature. In field testing to date, NIALMS has accurately identified most large, common household appliances, such as refrigerators, ovens, water heaters, and furnaces.

The NIALMS master station software can disaggregate the load data and report individual appliance electricity consumption as well as whole-house power use trends. Several data formats designed to meet utility needs in load surveying and forecasting and in customer billing services have been developed during the field tests and will be available in the commercial release of the residential version. These include such easy-to-understand displays as pie charts and time-series graphs. In addition, electronic data transfer will be available in Excel and ASCII formats, with other formats expected to follow.

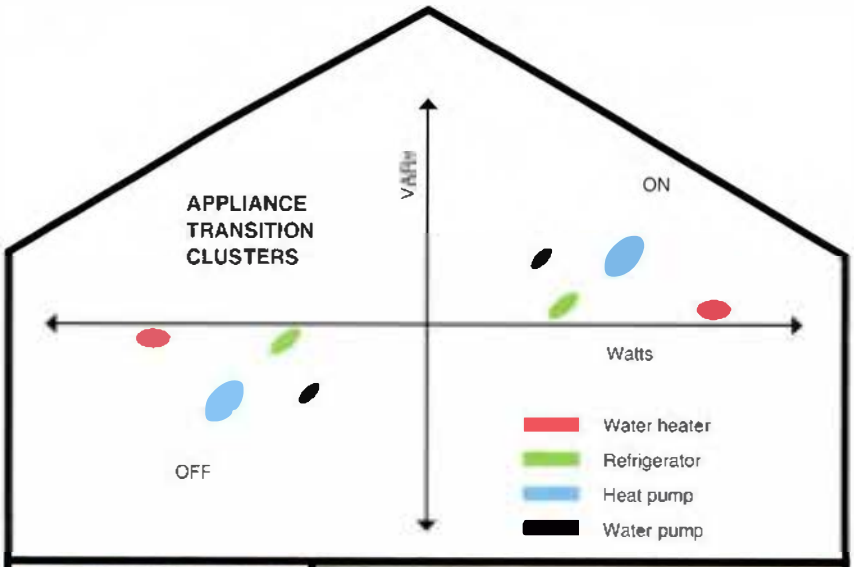
Mark Malmendier, the NIALMS product manager for Telog, says the residential version is expected to cost $1195 per recording monitor, with the NIALMS master station software (not including hardware) running around $8975. He says that so far, beyond the utilities involved in the beta testing, utility interest has come primarily from load researchers, who have traditionally used hardwired appliance monitoring to collect end-use data for rate-related filings.

"But we are detecting a growing interest in NIALMS from utility energy service marketing organizations," says Malmendier. Attracting their attention is not difficult, he adds, when "we point out that NIALMS provides extremely high grade information about how customers are using the utility's product. For utilities, it's almost like having a Nielsen ratings box on some customer meters."

Malmendier and Barry Ceci, Telog's president, note that the company is working on a prototype polyphase version of NIALMS for application at commercial and industrial utility customer sites. This version will not simply identify appliance signatures from time and magnitude patterns. It may, for example, have the capability to analyze and deconstruct overlapping harmonics of the power system frequency in order to rec-



HOW NIALMS WORKS **Telog Instruments' Non-Intrusive Appliance Load Monitoring System (NIALMS) features a recorder designed for easy installation between a utility meter box and a conventional kilowatthour revenue meter. From digitally sampled voltage and current measurements and time tags, the device records stepwise changes in real and reactive power above a programmed threshold. Voltage, current, and whole-house power use data are also recorded at specified time increments. The data are automatically retrieved over a telephone line (or other medium) for analysis with the NIALMS master station software. The software plots scatter data on a watt-VAR graph and compares on-off data clusters with a stored library of appliance signatures. To date, the system successfully identifies and tracks most common household appliances, including refrigerators, ovens, water heaters, and furnaces.**



ognize more-complicated multiple loads, including multistate appliances that are likely to require the development of new algorithms as well.

"We've chosen to pursue the residential market first, but we think that down the road the monitoring of loads in commercial buildings and at industrial customer sites will be an even greater market for the NIALMS technology," says Ceci, who notes a trade-off of sorts in potential applications for the monitoring system.

"The approach of deregulation and the rise of competition have reduced the market opportunities for NIALMS in DSM-related uses, on the one hand, but have created stronger opportunities on the marketing side, as utilities seek to get closer to their customers and offer them additional services. NIALMS not only gives utilities a way of providing customers with a disaggregated bill but also gathers information at the customer side of the meter that could be very useful and valuable to both the customer and the utility," says Ceci. He expects that after its initial commercial launch, NIALMS will undergo a continual evolution, with improved algorithms and

evolution, with improved algorithms and appliance recognition capabilities, lower cost, availability in a variety of models, and improved ease of installation.

Eventually, says Ceci, with the widespread availability of high-bandwidth communications links to homes and businesses, NIALMS could play a key role in integrating real-time (or nearly real-time) continuous monitoring and display of appliance use with up-to-the-minute time-of-use rate information from the utility. Automatic meter reading for billing and the like would also be possible.

Field tests already yield savings

Already, in utility field tests of the beta residential version, NIALMS has demonstrated an ability to provide information that can be used to diagnose problems with appliances. "It's been amazing how many times in the beta tests we've been able to identify misoperating appliances," says Ceci. "We've found a couple of faulty refrigerator compressors, a defective waterbed heater, an air conditioning system oil heater coming on in the summer, and an electric heater coming on beneath an air conditioning fan." Telog is using the data collected during the NIALMS beta tests to further develop the system's capabilities. And previously collected data are being reanalyzed with improved versions of the master station software.

Bob Jones, an R&D project manager with RG&E who is also the NIALMS project manager for ESEERCO, agrees that NIALMS "is really an amazing device. At each of the four houses where we have installed it, including mine and that of a former senior executive of the company, we've discovered ways to save a few hundred dollars a year. What is amazing is that NIALMS tracks large loads so accurately."

Adds Dave Laniak, former RG&E executive vice president and former chairman of the advisory council for EPRI's Information Systems & Telecommunications Business Unit, "NIALMS is the most exciting technology development I have seen in many years. It comes at a time when competition is growing and electric utilities are searching for ways to offer value-added services on the customer side of the meter. NIALMS provides that opportunity."

RG&E continues to field-test NIALMS in cooperation with Telog. And during the past year, seven other utilities began field tests of the monitoring system that are expected to provide a final round of user evaluation and feedback before the commercial release of NIALMS for residential applications. Those utilities are Buckeye Power, Consolidated Edison Company of New York, East Kentucky Power Cooperative, Entergy Corporation, Potomac Electric Power Company, Public Service Electric and Gas Company, and Southern California Edison Company.

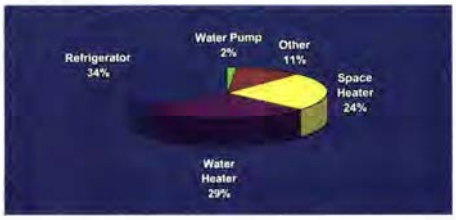
Jackie Lemmerhirt of Plexus Research, the contractor that is coordinating the field test program for EPRI, says NIALMS is performing well in detecting loads for two-state appliances, such as water heaters, air conditioning systems, pumps, and waterbed heaters. Both air-source and ground-source heat pumps are readily identified and tracked by NIALMS. She adds that the system also detects and tracks refrigerators, which are multistate appliances, but that its algorithms presently miss the electricity consumed during defrosting. Other multistate appliances, including dishwashers and clothes dryers, are tracked less well by the system's algorithms. A total of 140 different appliances are being monitored with NIALMS during the beta tests, and the resulting data are being compared on an hourly basis with data from parallel direct measurements.

As of last fall, the average difference between the NIALMS data on monthly electricity consumption and the data from direct metering was less than 15% for all appliances, with pumps and refrigerators showing less than 10% difference. (For whole-house electricity consumption, the NIALMS data came within 2% of the direct-metering data.) "In the final report on the beta testing, we hope to be able to give a firm indication of the accuracy achievable with NIALMS for a range of appliances," says Lemmerhirt, "so that a utility can better evaluate the cost-effectiveness of using NIALMS to monitor specific appliances." The test report is expected to include data on winter-related residential heating loads as well as summer cooling loads.

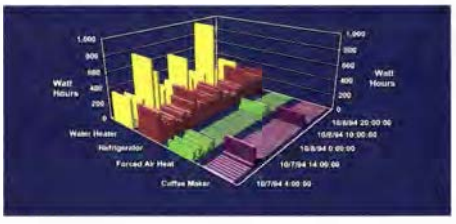
"I think NIALMS will be popular with utilities when it becomes commercially available," says Buckeye Power's Woller. "Considering its cost and its low labor requirement for installation and maintenance, the system is very attractive compared with conventional appliance monitoring, which usually involves setting up a lot of equipment in somebody's basement. The value of avoiding the inconvenience and disturbance to the customer is, I believe, equal to twice the cost of direct monitoring. Then there is the advantage of being able to

GRAPHIC DISPLAYS BRING NIALMS DATA TO LIFE **Using the NIALMS master station software, recorded load data can be disaggregated to report individual appliance electricity consumption, multiappliance comparisons, and whole-house power use trends. Several data formats developed during utility field tests will be available in the residential version of NIALMS, including easy-to-understand displays like pie charts and time-series graphs.**

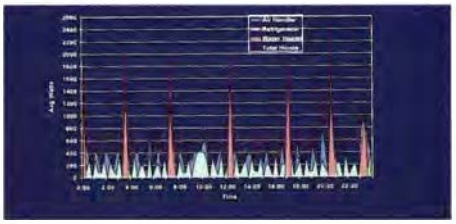
Household energy consumption by appliance



Time of use by appliance



Load profile



UTILITIES PUT NIALMS TO THE TEST

In cooperation with Telog and EPRI, seven electric utilities are field-testing NIALMS and are documenting its accuracy with data from parallel hardwired appliance monitoring. Each utility has installed NIALMS monitors at up to half a dozen customer sites. Critical utility and customer feedback from these field tests is helping not only to refine the precision and reliability of NIALMS but also to enlarge the database of appliance power profiles.

Installing a NIALMS recorder in Buckeye Power's service area

daily or weekly basis. If a problem develops, you know about it quickly. With conventional monitoring, you might not discover that you have a problem until you've already lost a large amount of data."

The convenience and the simplicity of NIALMS, combined with the value of its information output, impress Mike Keith, load research supervisor at East Kentucky Power Cooperative, a generation and transmission company for 18 rural electric cooperatives. "Having a device that we can put on a home and that allows us to look at individual uses of electricity without actually having to enter the home will be a boon. It will help us in any kind of end-use metering project; it could help resolve customer billing complaints; and it could be used for providing itemized billing. If you can give customers a breakdown of their electricity consumption, they will be more likely to conserve energy and think about how they use electricity."

At Southern California Edison Company, researchers are evaluating NIALMS in conjunction with ongoing tests of the commercially available Consumer Electronics Bus (CEBus) power line carrier–based system for communicating with appliances and monitoring household electricity use. Joe Kelly, an SCE senior research scientist, says that five houses that were already equipped with CEBus appliance and control monitors and whole-house utility meters were selected for the NIALMS field tests because that was an easy way to get the parallel metered appliance data necessary for evaluating the system's load-tracking accuracy. Kelly adds, however, that SCE is interested in pursuing further development of NIALMS with Telog and EPRI to make the monitoring system not just compatible with CEBus but capable of serving with CEBus as a control switch that could be used to remotely turn certain appliances on and off. "This is a likely area of future collaboration," he says.

Looking ahead

EPRI's Carmichael believes that beyond the initial residential market, the greatest commercial potential for NIALMS may lie in its capability for low-cost and remote, nonintrusive diagnostics of commercial and industrial loads like motors. "Where it could really pay off is with smaller, 10–50-horsepower motors for which it is now prohibitively expensive to take individual voltage, current, and vibration measurements." He says that the building energy control system manufacturer Honeywell has expressed interest in exploring the use of NIALMS in a control system as a feedback loop to verify the startup of small motors, such as those on HVAC fans.

EPRI is supporting exploratory research on the development of advanced technology for NIALMS with Telog, with MIT researchers, and with the computer scientist credited with the original discovery of the system's feasibility at MIT—George Hart, now a professor of computer science at Hofstra University. Hart is working closely with Telog to develop improved algorithms for recognizing and tracking multistate appliances—algorithms that could have applicability in commercial and industrial customer settings as well as in residential settings.

Understanding the nuances of the operating states of multistate appliances like dishwashers and incorporating those into advanced algorithms will involve "a deeper dimension of pattern recognition than is now being implemented in the residential NIALMS," says Hart. "We believe that multistate algorithms can be developed that will work with Telog's current hardware. Once the residential system is fully debugged, the development of improved software that would include multistate appliances would follow in a future release." Ultimately, EPRI research managers envision incorporating NIALMS technology into software that can be licensed by manufacturers of digital kilowatthour meters for inclusion in their products.

At MIT, electrical engineering professor Steven Leeb and architecture professor Les Norford are developing an advanced software design for dealing with more-complex loads at commercial and industrial sites. The researchers are using some MIT campus buildings as surrogates in exploratory work that is examining the detailed characteristics of overlapping electrical transients. The goal is to find ways of identifying incipient problems with such major loads as motors. ■

Further reading

Non-Intrusive Appliance Load Monitoring With Finite-State Appliance Models. Report for WO3030, prepared by George Hart, Hofstra University, February 1996. EPRI TR-105583.

Non-Intrusive Appliance Load Monitoring System. Brochure, January 1996. EPRI BR-106036.

Requirements for an Advanced Utility Load Monitoring System. Final report for RP2562-10, prepared by New England Power Service Company and Plexus Research, December 1989. EPRI CU-6623.

NIALMS has won a 1996 Innovation Award from Utility Automation *magazine for being the most valuable demand-side management product of the past year. To order NIALMS, contact Mark Malmendier at Telog Instruments, (716) 742-3000.*

Background information for this article was provided by Laurence Carmichael of the Customer Systems Group's Information Systems & Telecommunications Business Unit.

CONTRIBUTORS

Technical sources for Journal feature articles

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PURCELL

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The Road Ahead for EV Batteries (page 6) was written by Taylor Moore, *Journal* senior feature writer, with the guidance of **Fritz Kalhammer,** coordinator for science and technology at EPRI. Before assuming this part-time position in March 1994, Kalhammer organized and directed EPRI's longer-term core research programs as vice president of strategic R&D. Earlier he helped organize the Institute's end-use R&D; he headed the Energy Management & Utilization Division from 1979 to 1988 and was named an EPRI vice president in 1983. Before joining the Institute in 1975 to direct energy storage and fuel cell research, Kalhammer managed the electrochemistry program at Stanford Research Institute. Still earlier, he worked at Philco Corporation and at Hoechst in Germany. Kalhammer attended the University of Munich, where he earned BS and MS degrees in physics and a PhD in physical chemistry. ■

Mowing Down Pollution (page 16) was written by Leslie Lamarre, *Journal* senior feature writer, with assistance from **Gary Purcell,** who manages infrastructure and vehicle interface R&D in the Electric Transportation Business Unit of the Customer Systems Group. Purcell joined EPRI in 1977 after 15 years with Lockheed Missiles & Space Company, where he specialized in aerospace vehicle temperature controls. A mechanical engineer, Purcell received an MBA from Pepperdine University. ■

Load Monitoring Enters the Digital Age (page 24) was written by Taylor Moore, *Journal* senior feature writer, with assistance from the Customer Systems Group's **Laurence Carmichael,** manager for customer interface and controls R&D in the Information Systems & Telecommunications Business Unit. Carmichael joined EPRI in 1985 after two years as a project manager with Science Applications International Corporation. Earlier he was a project manager with Systems Control and worked as a principal engineer with General Electric Company's nuclear utility operation in San Jose, California. Carmichael received a BS degree in chemical engineering from the University of California at Berkeley and an MS degree in mechanical engineering from Stanford University. ■

Nonroad EVs

Faster Charge May Be on the Way for Electric Lift Trucks

Of all nonroad electric vehicles, electric lift trucks, or forklifts, represent the largest single load for electric utilities. Yet in this country electric lift trucks make up only 40% of the lift truck market. This compares with a 70% market share in Europe.

EPRI researchers investigated the limited penetration of the U.S. market and found one deterrent to be that the charging systems currently in use take 8 hours to fully charge lift truck batteries. In 24-hour operations like warehouses and automobile manufacturing plants, such a long charging time is a major drawback. Typically, such operations must keep two extra battery packs for each lift truck; these are charged while a third pack is in use. Not only are the extra batteries expensive, but they also take up space.

A more convenient alternative may soon be available. EPRI is working with Norvik Traction Inc. of Ontario, which has developed a new system it says will quick-charge lift truck batteries in 20 to 30 minutes. Such a rapid charging capability would enable workers to charge the trucks while on a break or even between shifts. Through an EPRI project that got under way early this year, Norvik has supplied one of its quick-charging systems for testing at a Ford plant in Dearborn, Michigan. The tests will continue for approximately six months.

According to Gary Purcell, EPRI's manager for the project, three lift trucks are being compared: a conventional model (representing the current charging practice) and two new lift trucks manufactured by Clark Materials Handling of Lexington, Kentucky. The Norvik quick-charging system is being used with the new Clark trucks, one of which has a conventional battery and the other an advanced lead-acid battery manufactured by Electrosource. It is expected that charging will be even faster with the advanced battery.

Each lift truck is instrumented to collect the necessary data. Positive results for the charger, the new lift truck, or the Electrosource battery could mean big business. As Purcell points out, Ford alone has 100 facilities that employ lift trucks in the United States. "That's a lot of lift trucks and a lot of sales," he says. Final results from the tests are expected late this year.

■ *For more information, contact Gary Purcell, (415) 855-2168.*

Energy Efficiency

Project Promises Improved Milk Quality for Dairy Farms

Hawaii may be great for surfing and sunbathing, but producing quality milk in paradise isn't as easy as it might seem. One problem is the tropical climate, which can make milk chilling very challenging. Through a joint project with Hawaiian Electric Company (HECO) and the state's Department of Agriculture, EPRI is working to improve the energy efficiency of milk production and to enhance the quality of milk at two island dairies.

Dairy farming is a competitive business on the islands of Hawaii, where residents can always opt for milk imported from California. Over the past two decades, the number of dairies has dwindled considerably; only 11 remain today. Among them are the Mountain View Dairy Farm, with 1000 head of cattle, and the Evergreen Hillside Dairy, with 300—both located in the town of Waianae on Oahu.

Traditionally, both businesses have relied on the type of chilling system used by most U.S. dairy farms, one that pumps warm milk to a storage tank for cooling. But cool-

ing a tankful of body-temperature milk in the sweltering heat is a time-consuming process, during which the milk's quality can deteriorate. As an alternative, HECO, with support from EPRI and Hawaii's Department of Agriculture, is investigating a system that cools milk as it flows toward the tank, reducing its temperature to 38°F by the time it enters the refrigeration vessel.

HECO plans to install such "instant" milk-cooling systems at the Evergreen and Mountain View dairies this spring. Paul Fetherland, HECO's manager for the project, notes that the Mountain View system will feature a packaged chiller manufactured by Carrier Corporation—a chiller typically used in heating, ventilating, and air conditioning applications. Ordinarily, milk-cooling systems are purchased custom-made from dairy equipment suppliers, but Fetherland explains that "because of the large scale of this project, we didn't want to buy a custom piece of equipment that would require servicing by mainland technicians." (Technicians for standard HVAC equipment are widely available in Hawaii.) Researchers from the Cornell University Agricultural Energy Program (CAEP) will monitor the two chilling systems and the quality of the resulting milk for one year.

In the meantime, HECO and CAEP are pursuing other electricity-related enhancements. For instance, they plan to incorporate heat recovery into the Mountain View system so that the chiller can also provide hot water and reduce the dairy's use of propane, which is expensive on the island. And in an earlier phase of the project, HECO tapped the expertise of CAEP to install adjustable-speed drives on vacuum pumping systems at the two dairies. Initial results indicate that the drives have reduced energy use at the dairies by about 40%.

■ *For more information, contact Ammi Amarnath, (415) 855-2548.*

Water Treatment

EPRI Tests New System for Cleaning Water From Manholes

EPRI has begun comprehensive tests of a new curbside unit for treating water pumped from the manholes used to access electrical lines. Currently utilities simply discharge the water—typically ranging from 500 to 4000 gallons from a single underground vault—directly into the streets or storm drains. But in some urban areas, these waters have been found to contain high amounts of oil, grease, and metals.

The new mobile water management unit is a 17-by-8-foot trailer that eliminates the need to collect and transport the water from manholes to a central treatment facility—a cumbersome and expensive task. Developed in 1995 through a joint project with the Potomac Electric Power Company, the trailer contains everything needed to treat and then discharge the water on-site. Treatment components in the trailer include a clarifier for removing oil and grease and for settling solids, a filtering system for removing small particles containing metals, and a granular activated carbon adsorption system for final cleanup. A diesel generator supplies the power to drive pumps and other components of the system, which can sustain a flow-through rate of 50 gallons per minute. The mobile system was designed to be usable by typical utility workers and does not require extensive training. It can be safely transported from location to location and is operable in all seasons and weather conditions.

The EPRI-PEPCO collaboration started with the collection and testing of samples from a number of the utility's Washington, D.C., manholes. Once the target contaminants were identified, laboratory treatability studies were conducted to select treatment processes for dealing with those substances in the simplest, most effective way, using components suitable for a compact, mobile housing. A prototype unit was designed and assembled, and initial testing was conducted late in 1995; the results enabled researchers to refine the system.

Additional tests of the prototype trailer got under way early this year and are expected to be completed this spring. After that, PEPCO will use the prototype unit for on-site water treatment as the need arises in the course of its daily operations. During the first full year of the trailer's operation at PEPCO, EPRI plans to conduct more-comprehensive performance testing that includes a random sampling program. Data on system durability, operability, and maintenance requirements will also be collected.

■ *For more information, contact Ishwar Murarka, (415) 855-2150.*

Georgia Power, Southern Company Services Use PCTRANS to Evaluate MGP Site Remediation

At the sites of former utility manufactured gas plants (MGPs), the slow migration of many organic compounds in soil and groundwater complicates both site remediation and the evaluation of remediation effectiveness. The compounds may take decades to migrate to treatment and monitoring wells. This slow migration makes it difficult, and often impossible, to pilot-test remediation strategies within a reasonable time.

Recently, Georgia Power Company and Southern Company Services—both subsidiaries of the Southern Company—needed a way to make long-term predictions as part of their evaluation of remediation effectiveness at a former MGP site where some contaminated soil had been removed and the remainder stabilized with cement. It was necessary to demonstrate the long-term effectiveness of that strategy in order to avoid having to perform long-term site monitoring. The companies used EPRI's PCTRANS™ groundwater flow and contaminant transport model to simulate the long-term migration of organic compounds at the site, thereby demonstrating the effectiveness of the in situ stabilization and saving an estimated $1.1 million in monitoring costs.

Modeling with PCTRANS helped establish in situ stabilization as a cost-effective remedy for MGP sites (its cost was about one-third that of traditional remedies for contaminated soil and groundwater). Applying the model also helped Georgia Power understand the hydrologic impacts of in situ stabilization at the site, which, in turn, will help the utility design similar remedies at other sites. PCTRANS predictions of a very slow rate of groundwater movement within the stabilized soil led to the conclusion that there would be sufficient time for biodegradation to act on organic compounds within the zone. This conclusion helped Georgia Power determine that the chosen remediation strategy at the site was effective, that monitoring could be discontinued sooner than planned, and that no further remediation was necessary.

■ *For more information, contact Dave McIntosh, (415) 855-7918.*

Center Helps Industries Meet Environmental Requirements and Improve the Bottom Line

The Electrotechnology Applications Center (ETAC) at Northampton Community College in Bethlehem, Pennsylvania—a partnership between Pennsylvania Power & Light Company and the college in collaboration with EPRI and the state of Pennsylvania's Ben Franklin advanced technology program—is helping local manufacturers implement environmentally sound technologies that also improve productivity.

The first of 15 regional centers that EPRI expects to develop with member companies over the next five years, ETAC is an example of the way electric utilities are giving industrial customers access to advanced expertise and technology under EPRI's Industrial Technology Center Partnership. "ETAC will help transfer technology directly to utility customers and make those customers more competitive," says EPRI's Clark Gellings, vice president for customer systems.

The center, which counts several successes in its first year of operation, focuses on the application of infrared and ultraviolet drying and curing systems to reduce the use of solvents containing volatile organic compounds (VOCs) in manufacturing processes. ETAC's 4000-square-foot laboratory houses an electric convection oven, infrared lamps, an ultraviolet curing section, spray booths, cleaning devices, and a variety of postcoating testing equipment.

Resilite Sport Products Company, the nation's leading producer of athletic mats, is one of the companies that has turned to ETAC for assistance in complying with new federal clean air standards. Although Resilite had been in compliance with earlier standards, it vaulted into the top 10 sources of air pollution in Pennsylvania after new Environmental Protection Agency regulations recently took effect. The Sudbury, Pennsylvania, company had been making wrestling and gym mats

for 35 years by spraying large pieces of foam with vinyl-based paint and hanging them to air-dry. The process required a large amount of paint and resulted in a commensurately large amount of VOC emissions from the paint solvent.

ETAC helped Resilite convert to a water-based paint that not only meets EPA regulations but provides other benefits: less shrinkage of mats (which means savings on base materials) and an improved work environment for employees. More recently, ETAC has been working with Resilite to use infrared drying techniques to reduce the drying time of the new water-based coatings.

G. Keith Sames, Pennsylvania Power & Light's program director at ETAC, notes that many of the utility's industrial customers are small firms that are struggling to comply with tougher new federal pollution limits and, without help, may simply close or move to other parts of the world. "That would mean a loss of jobs for Pennsylvania and fewer customers for PP&L," he adds. To provide assistance that was more than just advice, PP&L collaborated with EPRI to develop ETAC as a place where manufacturers could get hands-on access to new technology. Says Tom Shaughnessy of Northampton Community College, ETAC's director, "The response has been very enthusiastic. Industrial firms are lining up to take advantage of the facility."

According to William Smith, EPRI executive project manager, "ETAC represents the vanguard of a network of local utility-sponsored centers across the country. Successes achieved there are being relayed to utilities and manufacturers in other parts of the country." EPRI has recently made agreements with TU Electric, Metropolitan Edison Company, and Pennsylvania Electric Company to establish centers in their areas.

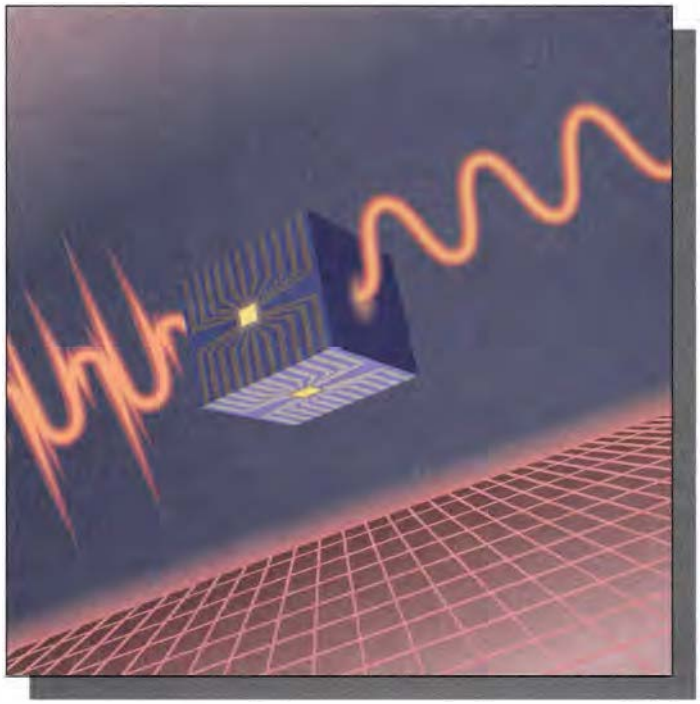
■ *For more information, contact William Smith, (415) 855-2415.*

EPRI and Centerior Energy Collaborate on Power Quality Service Center

For process industries, which count on continuous power to meet production goals, help with power quality problems is now just a phone call away. EPRI and Centerior Energy Corporation have created a regional service center near Cleveland to address power quality issues faced by process industries. The Centerior Power Quality Service Center (CPQSC) makes use of EPRI research on both sides of the meter to solve power quality and equipment sensitivity problems.

"Customers call us when they have equipment problems resulting from high or low voltages, transients, harmonics, or unknown causes. Most of the problems are related to the building's wiring or equipment, and we solve them during our first visit," says Nick Lizanich, manager of the center. "Other situations call for extended monitoring of performance characteristics over a period of time."

CPQSC will operate as a technology testing, training, and communications center, addressing problems specific to process industries, such as rubber and plastics, food processing, textiles, chemicals and petroleum, steel, and pulp and



paper. The staff of power quality engineers and technicians will conduct technical seminars, publish educational materials, and carry out R&D activities. As part of the power quality service network, CPQSC will have access to the research of other EPRI centers and will share its own findings.

"In a time of increasing use of power electronics, utilities want to supply very high quality power to support the myriad of electrotechnologies and devices now available to their customers," says Clark Gellings, EPRI vice president for customer systems. "With the help of power quality service centers like Centerior's, utilities are able to provide a better analysis of electrical disturbances and offer cost-effective solutions."

CPQSC is currently monitoring power quality problems at six rubber and plastics plants in Ohio. In another effort, an architectural engineering handbook will soon be published to help educate facility operators about the proper way to hook up equipment and to design and install plant distribution systems. Other future training tools will include a power quality design guidebook for commercial buildings and courses based on the two-volume EPRI technical report *Power Quality for Electrical Contractors: Applications Guide* (TR-101536).

"We look at this center as an example of how EPRI can partner with one of its members to help not only that member but all U.S. utilities," says Karl Stahlkopf, EPRI vice president for power delivery.

■ *For more information, contact Marek Samotyj of EPRI, (415) 855-2980, or Nick Lizanich of Centerior Energy, (216) 520-9594.*

Illinois Power Tests Alternative Biocides for Controlling Zebra Mussels

First detected in Lake Erie in the late 1980s, zebra mussels have since spread throughout the Great Lakes and into surrounding rivers. The mussels can clog cooling-water systems if not controlled. Power plant operators have developed a variety of treatments to avoid this problem.

In 1993, Illinois Power Company developed a contingency plan for its power plants on the Illinois and Mississippi Rivers in anticipation of the mussel's appearance. The plan was based on conventional chlorination techniques. But when the rivers flooded in the summer of 1993, swift action was required to prevent cooling systems from becoming plugged due to zebra mussel infestation of the intake structures. The utility sought an alternative to the expensive chlorination systems used at other power plants.

EPRI studies of zebra mussels indicated possible control methods that were more cost-effective and less harmful to the environment than continuous chlorination systems that use hypochlorite. Chemical companies have developed biocides designed to act as a shock treatment on zebra mussels, thereby controlling their population growth more cost-effectively than conventional chlorination. Illinois Power worked with EPRI and the Illinois Environmental Protection Agency to develop a treatment testing plan that would demonstrate the effectiveness of these alternative biocides. Two biocides—chlorine dioxide and Clam-Trol—were initially proposed. Chlorine dioxide was tested in 1994, but a formulation of Clam-Trol was not approved by the Illinois EPA for testing until 1995.

Illinois Power conducted five tests of chlorine dioxide at various residual concentrations and river water temperatures. The two- and three-day tests showed that chlorine dioxide could effectively control zebra mussels. On the basis of the results, mortality rates greater than 90% were predicted for periods of moderate water temperature. The cost savings over chlorination systems were estimated to be about $150,000 a year. A report on the chlorine dioxide testing (TR-105202) is available from the EPRI Distribution Center.

The reformulated Clam-Trol, CT-2, demonstrated 100% mortality for the zebra mussels in an 8-hour test. CT-2 does not require on-site mixing as does chlorine dioxide, and its cost per treatment is about half the cost of that biocide. Compared with conventional chlorination, the use of CT-2 is estimated to save about $275,000 a year. A report on the CT-2 testing is expected to be published this spring.

■ *For more information, contact John Tsou, (415) 855-2220.*

Air Quality

Tropospheric Ozone Research in the Northeast

by Peter K. Mueller, Environmental & Health Sciences Business Unit

A multiyear field study is gathering and analyzing air quality, meteorological, and emissions data to improve scientific understanding of the processes contributing to tropospheric ozone pollution in the northeastern United States. The data are helping researchers to determine the relative contributions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) to ozone formation and accumulation in the region, and to document the impact of imported ozone and its precursors on local ozone concentrations. Findings will support the evaluation of predictive models for assessing ozone management options in the Northeast. Results will also be integrated into the North American Research Strategy for Tropospheric Ozone (NARSTO), a comprehensive continental-scale program of research and coordination. NARSTO-Continental covers conceptually several regional studies that were started before NARSTO was established.

Complex regional problem

Tropospheric ozone pollution is among the most pervasive and persistent air quality problems facing the regulatory, scientific, and industrial communities. In many regions of the United States, ozone concentrations still exceed the current National Ambient Air Quality Standard (NAAQS)—conventionally stated as 120 ppb—despite the expenditure of tens of billions of dollars during the past two decades on reducing NO_x and VOC emissions.

In the 1960s and early 1970s, ozone pollution was thought to be a localized urban airshed problem. Subsequent studies have revealed the scale and nonlinear complexity of factors influencing the occurrence of ozone in the lower atmosphere (troposphere). This is the scientific picture that has emerged: during three or four widespread meteorological situations each year, there may be large areas of elevated ozone concentrations, with embedded urban hot spots that exceed the NAAQS for one or more hours on some days. These episodes arise from multiple causes—including the emission of NO_x and VOCs within urban and industrial areas; the importation of ozone and its precursors by winds from rural and urban areas in adjacent, or even distant, airsheds; and the accumulation of ozone and precursors from previous days.

Improvements in sampling networks and instrumentation have helped fill in the picture. Researchers have begun to elucidate the photochemistry of the rural atmosphere and to observe complex temporal and spatial (including vertical) patterns in ozone and precursor concentrations. Some of these findings have changed our perceptions and conceptual models of tropospheric ozone phenomena. The complexity of ozone formation, transport, and accumulation processes and their interactions highlight the difficulties of developing equitable and cost-effective emissions management strategies.

Mandated modeling

Title I of the 1990 Clean Air Act Amendments sets deadlines for attaining national air quality standards for ozone concentrations by controlling emissions of NO_x and VOCs. The act specifies that "moderate" nonattainment areas come into compliance by 1996 (some may get one- to two-year extensions); "serious" areas by 1999 (e.g., Atlanta, El Paso, parts of New England, central California, the District of Columbia); "severe A" by 2005 (e.g., Baltimore, Philadelphia, Sacramento); "severe B" by 2007 (e.g., New York City, Chicago, Houston, Milwaukee); and "extreme" by 2010 (Los Angeles and vicinity).

Title I requires states with serious, severe, and/or extreme ozone nonattainment

ABSTRACT *Tropospheric ozone pollution is a complex regional problem that can be managed when understood in the context of the region in which it occurs. One key to improved understanding is the acquisition of sufficient atmospheric data to characterize the chemical, meteorological, biological, and other processes involved in ozone accumulation and to evaluate photochemical models that represent these processes. Many public and private organizations are participating in a major multiyear field study that is obtaining and analyzing data to improve our understanding of ozone source-receptor relationships in the northeastern United States. EPRI is providing coordination for this project. Results from the study will support model evaluation and the timely development of cost-effective emissions control strategies.*

Organizations Supporting NARSTO-Northeast

Allegheny County (Pennsylvania) Health Dept.
Allegheny Power System
American Electric Power Service Corp.
American Petroleum Institute
Atlantic Electric
Baltimore Gas and Electric Co.
Canadian Atmospheric Environmental Service
Connecticut Dept. of Environmental Protection
Consolidated Edison Co. of New York
Coordinating Research Council
Delaware Dept. of Natural Resources and Environmental Protection
District of Columbia Dept. of Consumer and Regulatory Affairs
Du Pont de Nemours & Co.
Eastman Kodak Co.
Electric Power Research Institute
Empire State Electric Energy Research Corp.
General Motors Corp.
GPU Service Corp.
Long Island Lighting Co.
Maine Dept. of Environmental Protection
Maryland Dept. of the Environment
Massachusetts Dept. of Environmental Protection
Mid-Atlantic Regional Air Management Association (MARAMA)
Mobil Oil Corp.
National Oceanographic and Atmospheric Administration
National Park Service
New England Electric System
New Hampshire Dept. of Environmental Services
New Jersey Dept. of Environmental Protection
New York Dept. of Environmental Conservation
New York State Electric & Gas Corp.
Niagara Mohawk Power Corp.
North Carolina Dept. of Environment, Health, and Natural Resources
Northeast States for Coordinated Air Use Management (NESCAUM)
Northeast Utilities
Ohio Edison Co.
Ozone Transport Commission
PECO Energy Co.
Pennsylvania Dept. of Environmental Resources
Pennsylvania Power & Light Co.
Philadelphia Air Management Services
Potomac Electric Power Co.
Public Service Electric and Gas Co.
Rhode Island Dept. of Environmental Management
Rochester Gas and Electric Corp
State University of New York at Albany
United Illuminating Co.
University of Maryland
U.S. Dept. of Energy
U.S. Environmental Protection Agency
Vermont Dept. of Environmental Conservation
Virginia Dept. of Environmental Quality

problems to use photochemical grid models to demonstrate the efficacy of alternative emissions management options. These large and complex computer models mathematically simulate the meteorological and chemical processes that govern the production and transport of ozone and are used to predict changes in air quality resulting from changes in emissions. Inputs to the models include simulations of emissions; of meteorological variables, such as wind, temperature, and sunlight; and of concentrations crossing domain boundaries. Although based on algorithms intended to approximate natural processes, these simulations must be made to represent reality much better than they do now.

Earlier legislation emphasized VOC reductions, which have helped curb ozone levels in large urban areas; Title I addresses both VOC and NO_x controls but emphasizes NO_x. As a result, the regulatory spotlight has widened to include fossil-fueled power plants, transportation vehicles, soil microorganisms, and other sources of NO_x emissions.

Need for field data

Given sufficient observational data to support the use of photochemical models, the credibility of these models as assessment tools could be substantially enhanced. In order to characterize the uncertainties in their constituent algorithms, the models must be evaluated by using meteorological and air quality data from the domain in which they are to be applied. For many parts of North America, however, the observational data available are insufficient to corroborate model performance.

EPRI has supported numerous research efforts designed to obtain atmospheric data to improve the evaluation and refinement of models, develop model components, and enhance scientific understanding of tropospheric ozone. For example, EPRI cosponsored research that has generated rich data sets for California's San Joaquin Valley, the Lake Michigan area, and various parts of the southern and southeastern United States. These data continue to support the development of an advanced emissions- and observations-based modeling system that increases the scientific credibility of emissions control assessments.

One U.S. area in need of additional observational data to support modeling is the Northeast Ozone Transport Region (known as the OTR), a multistate area stretching from Virginia to Maine. This region faces deadlines for an ozone control plan but lacks specific information on the chemical climatology of ozone formation, transport, and accumulation—information needed to view model outputs with confidence. For stakeholders in the OTR, this situation could result in onerous, unnecessarily stringent controls with unpredictable environmental results.

To provide the information to fill the knowledge gaps, public and private stakeholders in the Northeast sought EPRI's assistance in planning and coordinating a major field study to obtain and analyze observational air quality data for the OTR. The multiyear study, called NARSTO-Northeast, is an initial thrust of the larger NARSTO program, which provides a coordinating umbrella for all ozone research conducted across the continent. Like the continental NARSTO effort, the northeastern study is cosponsored by numerous public- and private-sector organizations representing the principal stakeholders involved in the ozone nonattainment issue.

NARSTO-Northeast is addressing the following issues:

- Meteorological processes leading to ozone episodes
- Mixed-layer structure and transport patterns
- Spatial differences in the ozone formation potential of VOCs and NO_x
- Importance of agricultural and other nonurban sources
- Relationship between emissions inventories and observed ambient precursor concentrations
- Reasons for differences between simulated and observed ozone levels
- Long-term trends in ozone and its precursors
- Benefits and limitations of various predictive models
- Effectiveness of precursor management practices

During the summer ozone seasons of 1994 and 1995, NARSTO-Northeast researchers—together with the states, the U.S. Environmental Protection Agency, and the U.S. Department of Energy—used airborne and ground-based instruments to collect meteorological and chemical data throughout the study domain. On the basis of these data, researchers have begun to develop hypotheses regarding factors driving ozone occurrences in the OTR.

Key issues, early results

Among the key issues in the OTR are the relative contributions of NO_x and VOC emissions to ozone formation, the role of transported ozone and ozone precursors, and the importance of biogenic VOCs and regional NO_x emissions to locally formed versus transported ozone. Data from the first campaigns are already helping researchers address these issues, with results that are relevant to ozone management decisions. For example, early findings have helped to clarify the temporal evolution of the atmospheric mixing height—the height of the layer above the earth's surface through which the mixing of heat, moisture, and emissions occurs.

Model-generated predictions of atmospheric chemical concentrations are very sensitive to mixing height. For example, when mixing-height profiles derived from different algorithms were run through the Urban Airshed Model IV (UAM-IV), model output indicated that VOC control would be preferred under one profile and NO_x control under another. Furthermore, none of the calculated mixing-height profiles matched the actual data on mixing heights obtained during the 1994 campaign through radar profiler and radio acoustic sounding system measurements. With additional mixing-height data from the 1995 campaign and data to be obtained in 1996, it will be possible to represent more accurately the physics in the mixing-height algorithms.

Transport and carryover

Data gathered in the NARSTO-Northeast measurement campaigns are enabling the spatial and temporal characterization of ozone, NO_y, and VOC levels, as well as associated meteorology across the Northeast. This information is essential for understanding how ozone and its precursors are transported from other areas to contribute to ozone buildup within the OTR. In addition, the research is documenting how accumulated ozone formed on prior days (carryover ozone) combines with transported and locally produced ozone to contribute to nonattainment episodes.

For example, some data from the 1995 campaign indicate the presence of a significant reservoir of carryover ozone aloft over the region in the early morning hours. This carryover ozone is available for mixing down to the surface when the rising sun promotes air movement. In urban areas, this ozone tends to be removed by nitric oxide produced by combustion at ground level while photochemical reactions begin to form ozone anew. Determining the origins of this carryover ozone and the extent to which it influences ozone occurrences is an ongoing challenge to researchers and a key objective of the NARSTO-Northeast study. Wind profiler measurements and other data, including data collected with aircraft, should reveal what fraction of the carryover is transported from other areas versus what fraction is produced locally. These findings will help in assessing the regional extent of interactive and coordinated emissions management practices that would optimally achieve compliance with the NAAQS.

Future work

Observational data obtained in the measurement campaigns are being subjected to a rigorous quality assurance process and will become accessible on the Internet.

In 1996, investigators from the Southern Oxidants Study plan to use NARSTO-Northeast data sets to test their development of observations-based modeling techniques.

Longer-term goals for NARSTO-Northeast (beyond 1997) include testing predicted changes in air quality with changes in emissions inventories; evaluating and improving the accuracy of photochemical models; and monitoring trends, over and above the interannual variability in climate and in ozone and its precursors, to assess the effectiveness of emissions controls in reducing tropospheric ozone concentrations.

New Contracts

Project	Funding / Duration	Contractor / EPRI Project Manager
Customer Systems		
Market Opportunities for Heat Pumps in Residential Space Conditioning (WO2892-31)	$99,600 8 months	QDI Strategies / *T. Statt*
Development of Near-Optimal Cool Storage Controller (WO3280-53)	$129,100 15 months	Johnson Controls / *M. Khattar*
Testing of Inductive and Conductive Charging Systems and Couplers (WO3304-23)	$138,600 3 months	Wyle Laboratories / *G. Purcell*
Food Service Uniform Test Procedures (WO3563-1)	$75,000 15 months	Pacific Gas and Electric Co. / *W. Krill*
EPRI Healthcare Initiative: Assessment of an On-Site Medical Waste Disposal System Using Incandescent Technology (WO3742-10)	$250,000 4 months	Vance IDS / *M. Jones*
Decatur Memorial Hospital Study (WO3742-12)	$52,800 12 months	Henneman, Raulelsen and Associates / *M. Jones*
Water Purification Pilot Plant Studies (WO3743-13)	$850,000 24 months	City of Houston / *K. Carns*
Energy-Efficient Supervisory Control and Data Acquisition Systems for Water Utilities: Implementation Plan (WO3743-14)	$75,000 10 months	American Water Works Association Research Foundation / *K. Carns*
Nonchemical Water Treatment Evaluation (WO3743-16)	$79,600 6 months	Ahlgren Associates / *K. Carns*
Water Pollution Control Plant Energy-Monitoring Study (WO3743-18)	$50,000 12 months	City of Philadelphia / *K. Carns*
Optimal Siting and Control of Aerators in Secondary Treatment Systems for Wastewater (WO3743-19)	$50,000 12 months	Institute of Paper Science and Technology / *K. Carns*
Demonstration of Pulsed-Corona Technology for Mitigation of Volatile Organic Compounds (WO3762-3)	$180,000 15 months	Physics International Co. / *M. Jones*
EPRI Partnership for Industrial Competitiveness (EPIC): Plant Surveys for Baking Industry (WO3829-28)	$91,800 9 months	Edison Industrial Systems Center / *W. Smith*
EPIC: Plant Surveys for Canned/Frozen Food Industry (WO3829-29)	$91,800 9 months	Edison Industrial Systems Center / *W. Smith*
EPIC: Plant Surveys for Meat Products Industry (WO3829-30)	$91,800 9 months	Edison Industrial Systems Center / *W. Smith*
EPIC: Plant Surveys for Soft Drink Industry (WO3829-31)	$91,800 9 months	Edison Industrial Systems Center / *W. Smith*
EPIC: Plant Surveys for Printing and Printed Circuit Board Industry (WO3829-33)	$150,000 12 months	Chem Systems / *W. Smith*
Use of Infrared Heating With Rotational Molding (WO3878-3)	$290,000 13 months	Shoromaster / *W. Smith*
Pinch Energy Optimization Study (WO3879-12)	$150,100 8 months	American Process / *A. Amarnath*
New and Improved Technologies for Postharvest Handling and Curing of Peanuts (WO4807-3)	$150,000 36 months	University of Georgia Research Foundation / *M. Jones*
Chilled Aeration Project (WO4807-8)	$100,100 27 months	Purdue University / *M. Jones*
Electroosmotic Removal of Moisture for Enhanced Agricultural Drying (WO4807-9)	$111,800 24 months	University of Georgia Research Foundation / *M. Jones*
Electron-Beam and High-Pressure Processing of Food Products to Reduce or Contain Microorganisms (WO4827-4)	$300,000 36 months	Iowa State University / *A. Amarnath*
Utility Fleet Manager Assessment of Electric Vehicles (WO4852-1)	$609,000 12 months	Potomac Electric Power Co. / *E. Riddell*
Electric School Bus Demonstration (WO4861-1)	$134,900 38 months	Alabama Power Co. / *E. Riddell*
PQPager: Voice-Mail-Like Power Quality Monitor (WO4875-1)	$160,100 17 months	Basic Measuring Instruments / *S. Bhatt*
In-Vehicle Battery Performance Testing Database Management (WO4882-2)	$68,200 12 months	Dowgiallo Enterprises / *R. Swaroop*
Small Commercial Energy Management Systems (WO4883-1)	$368,500 17 months	Southern California Edison Co. / *L. Carmichael*
Advanced Central Community Geothermal Heat Pump System (WO4884-1)	$700,000 13 months	Southern California Edison Co. / *C. Hiller*
Potential Effects of Single-Phase Electronics-Based Loads on Power System Distortion and Losses (WO4887-1)	$158,000 17 months	University of Texas Austin / *B. Banerjee*
Advanced Energy Management Systems (WO4892-1)	$700,000 24 months	Southern California Edison Co. / *L. Carmichael*
Commercial Data Leveraging (WO4899-2)	$180,000 4 months	RLW Analytics / *R. Gilman*
Environment		
Histologic Preparation and Histopathologic Evaluation of Tissues From Mice Exposed to 60-Hz Magnetic Fields (WO2965-33)	$305,200 24 months	Pathology Associates / *C. Rafferty*
Modeling of Particle Deposition in Human Airways (WO3189-10)	$105,500 34 months	University of Delaware / *P. Saxena*
Study of Background Polycyclic Aromatic Hydrocarbons (WO9100-2)	$83,700 12 months	Meta Environmental / *I. Murarka*
North American Research Strategy for Tropospheric Ozone (NARSTO)–Northeast: Carbonyl Sampling and Analysis (WO9108-8)	$191,800 33 months	ATM AA / *P. Mueller*
Demonstration of CompMech Trout Model in California (WO9111-2)	$147,600 3 months	Lockheed Martin Energy Systems / *J. Mattice*
Hydro Basin Risk Manager (WO9112-1)	$139,300 10 months	Southern California Edison Co. / *R. Goldstein*
Multiple-Species-Reserve Management Research (WO9113-1)	$189,100 8 months	Southern California Edison Co. / *M. Fraser*
Demonstration of CompMech Fish Models in Idaho (WO9117-1)	$136,000 27 months	Lockheed Martin Energy Systems / *J. Mattice*
Generation		
Preventing Leakage in the Stand-to-Cup Connection of Water-Cooled Generator Stator Windings (WO2577-9)	$85,200 10 months	CC Technologies Laboratories / *J. Stein*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Field Testing of Lenenergo's Repowered 250-MW Supercritical Power Plant at St Petersburg, Russia (WO2818-11)	$135,000 12 months	Joseph Technology Corp./W. Piulle
Evaluation of Measurement Errors in Heat Rate and in SO_2 and CO_2 Emissions (WO2819-32)	$139,700 23 months	RMB Consulting and Research/C. Dene
Combustion Turbine Outage Reduction (WO2831-13)	$327,300 24 months	Combustion Turbine Technologies Co./ R. Frischmuth
PC-Based Tool to Assess Coal Property Impacts on NO_x (WO2916-33)	$75,700 6 months	Fossil Energy Research Corp./J. Stallings
PC-Based Tool to Assess Coal Property Impacts on NO_x (WO2916-34)	$138,000 6 months	SRI International/ J. Stallings
Pollution Prevention Workstation (WO3006-13)	$84,900 11 months	Radian Corp./ M. McLearn
Pollution Prevention Workstation (WO3006-14)	$85,000 12 months	Decision Focus/ M. McLearn
Resistance of Fly Ash Concrete to Deicing Salt Scaling (WO3176-19)	$125,700 25 months	CANMET/D. Golden
PISCES Water Toxics Characterization of Electric Utility Power Plants (WO3177-29)	$117,200 3 months	CH2M Hill/P. Chu
Value-Based Outage Planning Case Study (WO3288-9)	$275,000 18 months	Decision Focus/ M. Blanco
Enhanced Westinghouse Translator Demonstration (WO3384-41)	$484,100 15 months	TRAX Corp./M. Blanco
Computational Fluid Dynamics Modeling of the Effects of Fuel and Air Distribution in a Tangentially Fired Utility Boiler (WO3524-2)	$187,500 9 months	Southern Company Services/A. Facchiano
Hot Gas Filter Materials Testing (WO3639-3)	$286,700 10 months	Ahlstrom Pyropower/ R. Brown
Evaluation and Modification of Coal Quality Impact Model (WO3667-3)	$117,300 16 months	Black & Veatch/A. Mehta
SOAPP (State-of-the-Art Power Plant) Natural Gas Cofiring and Reburning Technology Module (WO3683-2)	$441,000 11 months	Sargent & Lundy/S. Pace
Living (Continuous Optimization) Maintenance Program for Hydro Plants (WO3974-1)	$181,000 11 months	ERIN Engineering and Research/C. Sullivan
Testing of the Ultramax Methodology NO_x Control in a Twin-Fired Unit (WO3982-2)	$191,700 28 months	Illinois Power Co./ J. Stallings
Siemens V94.2 Gas Turbine Optical/ Pyrometric Monitoring System (WO4022-1)	$368,200 31 months	PowerGen/W. Piulle
State-of-the-Art Particulate Control Upgrade Studies (WO4033-1)	$1,716,400 25 months	Duke Power Co./ R. Altman
Participation in Tree Genetic Engineering Research Cooperative (WO4062-3)	$112,500 60 months	Oregon State University/ J. Turnbull
GNOCIS (Generic NO_x Control Intelligent System) Demonstration at Duquesne Light (WO4131-1)	$126,900 21 months	Radian Corp./J. Stallings
Preparation of Wood and Waste Fuel for Cofiring (WO4134-1)	$283,000 16 months	New York State Electric & Gas Corp./E. Hughes
Tests of Wood Cofiring in Pulverized-Coal Boilers (WO4134-2)	$50,000 8 months	Pennsylvania Electric Co./E. Hughes
Wood Cofiring Tests at the Tennessee Valley Authority (WO4134-4)	$220,100 15 months	Foster Wheeler Environmental Corp./ E. Hughes
Ancillary Service in a Competitive Electric Power Market: Cost of Generating VARs (WO4161-3)	$53,500 7 months	Power Technology/ J. Stein
Pollutant Source Reduction Site Demonstrations (WO4209-1)	$750,000 25 months	Radian Corp./P. Radcliffe
Reduced-Airflow Demonstration at Low Load on Gas Fuel (WO4211-1)	$153,600 14 months	Carnot/K. Zammit
Integrated Hydro Diagnostic System (WO4239-1)	$310,900 18 months	BC Hydro/J. Birk
Milliken Limestone Evaluation (WO9017-5)	$66,000 7 months	Radian Corp./R. Rhudy
On-Line Corrosion Surveillance System (WO9044-1)	$85,800 9 months	CML, Inc./P. Radcliffe
GNOCIS Demonstration at Entergy (WO9059-1)	$110,300 15 months	Radian Corp./J. Stallings
Inspection and Metallurgical Evaluation of Waterwall Coatings at Allegheny Power (WO9060-3)	$119,900 51 months	Foster Wheeler Development Corp./ W. Bakker
NO_x Emission Controls for Roof-Fired Boilers (WO9086-1)	$1,305,000 7 months	American Electric Power Service Co./ A. Facchiano
Nuclear Power		
ESCORE-II: Next-Generation Fuel Behavior Code (WO2061-29)	$150,200 14 months	Anatech Research Corp./S. Yagnik
Molten Core Debris–Concrete Interaction Thermal Hydraulics (WO3425-7)	$132,800 18 months	Fauske & Associates/ M. Merilo
Upper-Bundle Hydraulic Cleaning Head Technology (WO3500-35)	$132,100 7 months	Foster-Miller/R. Thomas
Nuclear Power Plant Life Extension Baltimore Gas and Electrics Calvert Cliffs Plant (WO3698-3)	$229,100 6 months	Bechtel Group/J. Carey
Risk-Based Regulation Support: High Winds Hazard Study (WO3719-7)	$105,000 20 months	Yankee Atomic Electric Co./F. Rahn
Development of Solid-State Hydrogen Sensor (WO3790-1)	$100,000 12 months	Lockheed Martin Energy Systems/R. James
Effective Maintenance Through Condition Monitoring (WO3814-21)	$53,000 5 months	Maintenance & Operations Support Service/W. Johnson
Large Electrical Generator Maintenance Project (WO3814-22)	$75,900 15 months	Encotech/J. Sharkey
Low-Fluence Irradiation of Reactor Pressure Vessel Steels (WO3975-22)	$135,900 14 months	Materials Engineering Associates/R. Carter
Development of Steam Generator Upper-Bundle Hydraulic Cleaning (WO4151-1)	$237,200 7 months	Foster-Miller/R. Thomas
SENTINEL Demonstration and Code Enhancement (WO4188-1)	$120,000 7 months	ERIN Engineering and Research/P. Kalra

Project	Funding / Duration	Contractor / EPRI Project Manager
Optical Ultrasonic Thickness Gauge (WO4222-1)	$150,000 15 months	Karta Technology / *J. Spanner*
Feasibility Study of Flaws in Austenitic Piping (WO4222-2)	$62,400 7 months	J. A. Jones Applied Research Co. / *J. Spanner*
Chemical Decontamination of a BWR Using the NP/LOMI Process (WO4419-2)	$469,700 8 months	Southern Nuclear Operation Co. / *H. Ocken*
Flow Effects on Stress Corrosion Cracking and Electrochemical Potential (WO8401-4)	$684,900 13 months	General Electric Co. / *K. Ramp*
Hideout of Seawater Impurities (WOS520-17)	$150,100 19 months	AECL Technologies / *P. Millett*
Effect of Alternative Amines on Steam Generator Tube Fouling (WOS523-7)	$177,000 7 months	AECL Technologies / *P. Millett*
Fabrication of Stress Corrosion Cracks in Steam Generator Tubing (WOS530-16)	$55,000 2 months	Equipos Nucleares / *M. Behravesh*
Tube Integrity Methodology for Circumferential Cracking (WOS550-25)	$177,700 8 months	Aptech Engineering Services / *D. Steininger*

Power Delivery

Development of ROPES, an Optimal VAR Planning Tool (WO3578-2)	$400,000 23 months	BC Hydro / *D. Maratukulam*
Integrated Protection, Control, and Data Acquisition (WO3598-6)	$100,000 12 months	SRS Technologies / *J. Melcher*
Recloser Automation Pilot Project (WO3674-13)	$338,000 12 months	Public Service Co. of Colorado / *W. Blair*
Phasor Measurement Unit Installation and Operation (WO3717-2)	$241,600 15 months	Southern California Edison Co. / *R. Adapa*
Composite Towers Project (WO3748-13)	$595,800 25 months	Southern California Edison Co. / *A. Hirany*
Furaldehyde in Transformer Oil, Phase 2 (WO3970-2)	$358,900 23 months	Powertech Labs / *S. Lindgren*
Battery Monitoring System Cost Reduction (WO3984-2)	$329,500 10 months	MCM Enterprise / *B. Damsky*
High-Ampacity Thin-Wall Novel Polymer Cable (WO4192-1)	$530,500 35 months	Foster-Miller / *B. Bernstein*
High-Temperature Superconducting Fault Current Limiter (WO4213-1)	$459,500 36 months	Southern California Edison Co. / *R. Samm*
Integrated Electron Emission Field Sensor for Measuring Electric and Magnetic Fields (WO4213-1)	$331,500 24 months	Arizona State University / *D. Richardson*
Improved Circuit Breaker Monitor (WO4244-1)	$250,000 6 months	Consolidated Electronics / *B. Damsky*
PQ Pager: Voice-Mail-Like Power Quality Monitor (WO7015-1)	$160,100 17 months	Basic Measuring Instruments / *D. Richardson*
Powercor (Australia) Dynamic Voltage Restorer (WO7018-1)	$854,000 13 months	Westinghouse Electric Corp. / *A. Sundaram*
Energy Source Power System Stabilizer (WO7020-1)	$485,500 36 months	Southern California Edison Co. / *S. Eckroad*
SATCOMM Program and Application Project (WO7024-1)	$378,000 16 months	Southern California Edison Co. / *D. Richardson*
Maintenance Management Workstation (WO7027-1)	$74,000 2 months	Knoware Modeling Corp. / *P. Vujovic*
Wide-Area Measurements for Real-Time Control and Operation of Large Electric Power Systems (WO7029-1)	$396,200 14 months	Bonneville Power Administration / *D. Sobajic*
Cable Partial Discharge Location System Demonstration and Evaluation (WO7032-1)	$151,400 7 months	University of Connecticut / *R. Samm*
Aging of Ethylene Propylene Rubber Insulated Cables (WO7038-1)	$85,000 30 months	Cable Technology Laboratories / *B. Bernstein*

Project	Funding / Duration	Contractor / EPRI Project Manager
Implementation of Fully Integrated On-Line Dynamic Security Assessment Software (WO7039-1)	$1,204,400 28 months	Siemens-Empros / *P. Hirsch*
Dissolved Gas Analysis With EPRI Disposal Oil Sampling System (WO7914-7)	$72,400 24 months	Detroit Edison Co. / *D. Von Dollen*
Distributed Fiber-Optic Parameter Monitoring: Fiber and Installation Requirements (WO7932-1)	$71,600 14 months	Power Delivery Consultants / *D. Von Dollen*

Strategic R&D

Reliability Benefits of Distributed Resources (WO3436-13)	$66,000 7 months	Power Technologies / *V. Longo*
Technical Assessment Guide: Fundamentals and Methods of Risk Management and Decision Analysis Under Uncertainty (WO4322-3)	$50,000 12 months	Business Management Consulting / *G. Ramachandran*
Development of a Risk-Based Security Assessment Framework (WO8015-7)	$140,100 24 months	Iowa State University / *D. Sobajic*
Nonlinear Time-Series Analysis for Process Signal Validation (WO8015-11)	$160,000 25 months	University of California, San Diego / *R. James*
Construction and Preliminary Testing of a New Free-Air CO_2 Enrichment/Depletion System (WO8020-14)	$89,900 7 months	San Diego State University Foundation / *L. Pitelka*
Characterization of Environmental Isolates of *Pseudomonas cepacia* (WO8021-10)	$75,000 37 months	Ramot, Ltd. / *R. Goldstein*
An In-situ Nitric Oxide Sensor for Power Plant Control (WO8031-7)	$175,000 36 months	Colorado School of Mines / *J. Weiss*
Sapphire Fiber-Optic Sensors and Instrumentation Capable of Operation Above 1500 C (WO8031-8)	$131,400 38 months	Virginia Polytechnic Institute and State University / *J. Weiss*
Microwave Sensor for Nondestructive and Noncontact Estimation of Concrete Compressive Strength (WO8031-9)	$125,000 33 months	Colorado State University / *J. Maulbetsch*
Holocene Cyclicity, Climate Change Interpreted From Fluctuations in Alluvial Sedimentation (WO8035-6)	$100,000 18 months	University of North Dakota / *J. Maulbetsch*
Thin, Flexible Bifunctional Air Electrodes for Zinc-Air Cells (WO8061-3)	$175,000 9 months	Lawrence Berkeley National Laboratory / *F. Will*
Fabrication and Properties of Copper Indium Diselenide, Copper Indium Gallium Diselenide, and Related Materials for Solar Cell Applications (WO8063-5)	$271,500 36 months	University of Illinois Urbana / *T. Peterson*
Current Enhancement by Fission-Induced Columnar Defects in Mercury-Based High-Temperature Superconducting Materials (WO8065-11)	$60,000 12 months	IBM Corp. / *P. Grant*
Generic Object Model to Unify Heterogeneous Multiuser/Multivendor Networks (WO8507-3)	$50,000 5 months	Hypertek / *L. Carmichael*
Ceramics for Gas Turbines (WO8512-5)	$842,200 24 months	General Electric Co. / *W. Bakker*
Amorphous Silicon-Germanium Solar Cells (WO8513-1)	$150,000 29 months	Princeton University / *T. Peterson*
Superconducting Cable Construction and Testing (WO8514-1)	$3,359,000 48 months	Pirelli Cable Corp. / *D. Von Dollen*
Development of an Expert Systems Integration Methodology (WO9000-32)	$75,000 20 months	Kaman Sciences Corp. / *R. Pflasterer*
Technical Collaboration in High-Temperature Oxidation (WO9002-20)	$252,200 24 months	Lockheed Martin Energy Systems / *J. Stringer*
High-Current $YBa_2Cu_3O_x$ Tape Structures (WO9904-1)	$80,000 14 months	University of California Berkeley / *P. Grant*
Metal Contaminant Removal by Electroremediation (WO9907-1)	$139,400 10 months	Fluor Daniel / *F. Will*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. EPRI members that fund the business unit issuing a report can receive the report free of charge (or, in the case of bulk orders, for a nominal price). Domestic organizations not eligible for EPRI membership pay the listed price. Others should contact the Distribution Center for further information.

Two-page summaries of the reports announced here are available, free of charge, by fax. To receive a summary, call EPRI's Fax on Demand service (800-239-4655) from a touch-tone phone and follow the recorded instructions, using the fax identification number given in the report listing.

CUSTOMER SYSTEMS

Desk Book™: Residential End-Use Technologies (for Windows)

TR-105852 User's Manual (WO3512-17), license required
Contractors: Energy International, Inc.; Aptech Engineering Services, Inc.
Business Unit: Residential Technologies & Services
EPRI Project Manager: J. Kesselring
Fax ID: 24770

Structural Change and Futures for the Electric Utility Industry

TR-105144 Final Report (RP2343); $200
Contractor: Global Business Network
Business Unit: Retail Market Tools & Services
EPRI Project Manager: P. Sioshansi
Fax ID: 23816

Active Power Line Conditioning Methods: A Literature Survey

TR-105168 Final Report (RP2951-7); $200
Contractor: University of Texas, Austin, Department of Electrical and Computer Engineering
Business Unit: Power Quality
EPRI Project Manager: M. Samotyj
Fax ID: 24772

Proceedings: Residential Thermal Distribution Systems Workshop

TR-105311 Final Report (RP3512-21); $200
Contractors: Energen Consulting Group; ICF, Inc.
Business Unit: Residential Technologies & Services
EPRI Project Manager: S. Kondepudi
Fax ID: 24095

The Commercial Clothes Dryer Market: Market Structure and Opportunities for Microwave Dryers

TR-105497 Final Report (RP4001-19); $200
Contractor: National Analysts, Inc.
Business Unit: Retail Market Tools & Services
EPRI Project Managers: T. Hennebeerger, J. Kesselring
Fax ID: 34341

Contact Selection for Conductive Coupling of Electric Vehicle Charging Equipment

TR-105608 Final Report (RP3304-21); $200
Contractors: Hart, McMurphy & Parks; Underwriters Laboratories
Business Unit: Electric Transportation
EPRI Project Manager: G. Purcell
Fax ID: 24510

Customer Service and Marketing on the Internet

TR-105664 Final Report (WO3374); $200
Contractor: Hummel Consulting
Business Unit: Retail Market Tools & Services
EPRI Project Manager: P. Meagher
Fax ID: 24581

1994 Survey of Utility Demand-Side Programs and Services

TR-105685 Final Report (RP2884-2); $200
Contractor: Plexus Research, Inc.
Business Unit: Retail Market Tools & Services
EPRI Project Manager: P. Meagher
Fax ID: 24612

Information Technology Needs for Residential Value-Added Services

TR-105783 Final Report (RP3591); $300
Contractor: Analysis and Control of Energy Systems, Inc.
Business Unit: Residential Technologies & Services
EPRI Project Manager: S. Kondepudi
Fax ID: 24748

ENVIRONMENT

RESICALC 2.1 (Residential Magnetic Field Modeling Program): Addendum to the RESICALC 2.0 User's Manual

TR-104274-P1 Interim Report (RP4320-1); $200
Contractor: Enertech Consultants
Business Unit: Environmental & Health Sciences
EPRI Project Managers: R. Kavet, R. Takemoto-Hambleton
Fax ID: 25282

Magnetic Field Management for Overhead Transmission Lines: Potential Options for Low-Field Designs

TR-104413 Final Report (RP1717-6; RP2472-6, RP3959-2, -8); $200
Contractors: General Electric Co.; Sverdrup Corp.
Business Units: Environmental & Health Sciences; Transmission
EPRI Project Manager: R. Lordan
Fax ID: 22080

Childhood Brain Tumor Occurrence in Relation to External Power Lines and Other Sources of Residential Magnetic Fields

TR-105274 Final Report (RP2964-20); $200
Contractor: Fred Hutchinson Cancer Research Center
Business Unit: Environmental & Health Sciences
EPRI Project Manager: L. Kheifets
Fax ID: 24042

Constructed Wetland Treatment Systems for the Remediation of Metal-Bearing Aqueous Discharges

TR-105487 Final Report (RP2377-99); $200
Contractors: Woodlis Associates; BBI Associates
Business Unit: Environmental & Health Sciences
EPRI Project Manager: J. Goodrich-Mahoney
Fax ID: 24325

The Emission Allowance Market and Electric Utility SO_2 Compliance in a Competitive and Uncertain Future

TR-105490 (see listing under Strategic R&D)

SUBCALC 2.0 (Substation Magnetic Field Modeling Program): User's Manual

TR-105506 Computer Code Manual (RP4320-1); $200
Contractors: Enertech Consultants; Ohio State University, Department of Electrical Engineering
Business Unit: Environmental & Health Sciences
EPRI Project Managers: R. Kavet, R. Takemoto-Hambleton, R. Lordan
Fax ID: 25281

Proceedings: Wetlands and Surface Water Discharge Compliance Workshop

TR-105510 Proceedings (RP2377); $200
Contractor: Woodis Associates
Business Unit: Environmental & Health Sciences
EPRI Project Manager: J. Goodrich-Mahoney
Fax ID: 24363

Magnetic Field Management for Overhead Transmission Lines: Field Reduction Using Cancellation Loops

TR-105571 Final Report (RP3959-7); $200
Contractor: Enertech Consultants
Business Unit: Environmental & Health Sciences
EPRI Project Manager: R. Lordan
Fax ID: 24452

Human Melatonin in Magnetic Fields: Second Study

TR-105766 Final Report (RP4307-1); $200
Contractor: Midwest Research Institute
Business Unit: Environmental & Health Sciences
EPRI Project Manager: R. Kavet
Fax ID: 24728

GENERATION

Power-Electronic, Variable-Speed Wind Turbine Development: 1988–1993 (33M-VS Wind Turbine)

TR-104738 Final Report (RP1590-16, RP3062-2); $200
Contractor: J. A. Phillips & Associates
Business Unit: Renewables & Hydro
EPRI Project Manager: E. DeMeo
Fax ID: 23078

Innovative Systems for Waste Isolation and Containment

TR-104900 Final Report (RP1457-10); $10,000
Contractor: Radian Corp.
Business Unit: Environmental Control
EPRI Project Manager: M. McLearn
Fax ID: 23369

Use of FGD Gypsum and Bottom Ash in Roadway and Building Construction

TR-105236 Final Report (RP3176-11); $200
Business Unit: Environmental Control
EPRI Project Manager: D. Golden
Fax ID: 23978

Adjustable-Speed Drive: Harmonic Effects on Induction Motors, Vols. 1 and 2

TR-105323-V1, TR-105323-V2 Final Report (RP2624-1); $10,000 for set
Contractor: Rensselaer Polytechnic Institute
Business Unit: Fossil Power Plants
EPRI Project Manager: J. Stein
Fax ID: 24114

Performance and Cost of an IVOSDIG Biomass Gasification–Combined Cycle System

TR-105356 Final Report (RP3407-30); $200
Contractor: Stone & Webster Engineering Co.
Business Unit: Renewables & Hydro
EPRI Project Manager: J. Turnbull
Fax ID: 24156

Wellhead Deliverability of Natural Gas: Assembling the Evidence

TR-105405 (see listing under Strategic R&D)

The Emission Allowance Market and Electric Utility SO_2 Compliance in a Competitive and Uncertain Future

TR-105490 (see listing under Strategic R&D)

Primer on Maintaining the Integrity of Water-Cooled Generator Stator Windings

TR-105504 Final Report (RP2577); $10,000
Contractor: Ontario Hydro
Business Units: Fossil Power Plants; Nuclear Power
EPRI Project Manager: J. Stein
Fax ID: 24353

Laboratory Characterization of Atmospheric Fluidized-Bed Combustion By-Products

TR-105527 Final Report (RP2708); $10,000
Contractor: ICF Technology Inc.
Business Unit: Environmental Control
EPRI Project Manager: D. Golden
Fax ID: 24385

Coal Quality Field Test at Northeastern Unit 4 of Public Service Company of Oklahoma

TR-105565 Final Report (RP1400-25); $1000
Contractors: Electric Power Technologies Inc.; Southern Research Institute; Energy and Environmental Research Corp.; Southern Company Services; Fossil Energy Research Corp.
Business Unit: Fossil Power Plants
EPRI Project Managers: D. O'Connor, A. Mehta
Fax ID: 24441

On-Line Condenser Tube Cleaning System Demonstration

TR-105566 Final Report (RP1681-2); $10,000
Contractor: TU Electric
Business Unit: Fossil Power Plants
EPRI Project Manager: J. Tsou
Fax ID: 24442

Streamlined Reliability-Centered Maintenance at PG&E's Moss Landing Plant

TR-105582 Final Report (RP3854-2); $10,000
Contractors: Pacific Gas and Electric Co., ERIN Engineering and Research, Inc.
Business Unit: Fossil Power Plants
EPRI Project Manager: R. Pfiasterer
Fax ID: 24468

Performance of Electrostatic Precipitators and Fabric Filter Particulate Controls on Oil-Fired Electric Utility Boilers

TR-105592 Final Report (RP3453); $10,000
Contractor: RMB Consulting & Research, Inc.
Business Unit: Environmental Control
EPRI Project Managers: R. Altman, R. Chang
Fax ID: 105592

Emission Factors Handbook

TR-105611 Final Report (RP3177-9); $10,000
Contractor: Radian Corp.
Business Unit: Environmental Control
EPRI Project Manager: P. Chu
Fax ID: 24516

NUCLEAR POWER

Assessment of the Effective Dose Equivalent for External Photon Radiation, Vol. 2: Calculational Techniques for Estimating External EDE From Dosimeter Readings

TR-101909-V2 Final Report (RP3099-10); $200
Contractors: Texas A&M University, ENCORE Technical Resources, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 27307

Calvert Cliffs Nuclear Power Plant Life Cycle Management/License Renewal Program: Steam Generator Decision Analysis Case Study

TR-104732 Final Report (RP3343-15); $1000
Contractors: Baltimore Gas and Electric Co.; Janus Management Associates, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 23067

Nuclear Power Plant License Renewal Environmental Life Cycle Management Plan Manual: License Renewal Environmental Compliance

TR-104733 Final Report (RP3343-1); $5000
Contractors: Baltimore Gas and Electric Co., Halliburton NUS Corp.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 23069

PWR Molar Ratio Control Application Guidelines, Vol. 3: Hideout Return Evaluation Guidelines

TR-104811-V3 Final Report (RPS520); $10,000
Contractor: GEBCO Engineering, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: P. Millett
Fax ID: 25037

Probabilistic Fracture Analysis of Reactor Pressure Vessel Steels (Joint EPRI-CRIEPI RPV Embrittlement Studies)

TR-105027 Final Report (RP2455-18); $200
Contractor: Texas A&M Research Foundation
Business Unit: Nuclear Power
EPRI Project Manager: R. Carter
Fax ID: 23618

Proceedings: 1995 ASME/EPRI Radwaste Workshop

TR-105132 Proceedings (RP2414); $200
Contractor: Paul Williams and Associates
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
FaxID: 24396

Aging Management Evaluation of the Residual Heat Removal System for Westinghouse PWRs

TR-105135 Final Report (RP3075-9); $2000
Contractor: Westinghouse Electric Corp.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 23797

Evaluation of Environmental Qualification Period for Conax Electrical Penetration Assemblies

TR-105151 Final Report (RP3343-1); $3000
Contractors: Baltimore Gas and Electric Co.; ABB Asea Brown Boveri
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 23828

Aging Management Evaluation of Reactor Coolant System Supports for Westinghouse PWRs

TR-105272 Final Report (RP3075-9); $2000
Contractor: Westinghouse Electric Corp.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 24039

Effects of Respirators on Worker Efficiency

TR-105350 Final Report (RP3099); $200
Contractors: Yankee Atomic Electric Co., NEI
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24149

Comprehensive Low-Cost Reliability-Centered Maintenance

TR-105365 Final Report (RP2970-10); $20,000
Contractor: ERIN Engineering and Research, Inc.
Business Unit: Nuclear Power
EPRI Project Managers: D. Worledge, J. Gisclon
Fax ID: 24168

Proceedings: 1994 EPRI Workshop on PWSCC of Alloy 600 in PWRs (Parts 1 and 2)

TR-105406-P1–P2 Proceedings (RP3223-1); $1000
Contractor: Dominion Engineering, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: R. Pathania
Fax ID: 24233

Calvert Cliffs Nuclear Power Plant Life Cycle Management/License Renewal Program: Structure Scoping and Aging Management Review, Vols. 1–3

TR-105420-V1–V3 Final Report (RP3343-1); $5000 for set
Contractors: Baltimore Gas and Electric Co.; Grove Engineering, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: J. Carey
Fax ID: 24249

Primer on Maintaining the Integrity of Water-Cooled Generator Stator Windings

TR-105504 (see listing under Generation)

Instrumentation and Control Life Cycle Management Plan Methodology, Vols. 1 and 2

TR-105555-V1, TR-105555-V2 Final Report (RP3373-9); $50,000 for set
Contractor: Queue Systems, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: D. Wilkinson
FaxID: 24429

Proceedings: 1995 EPRI International Low-Level-Waste Conference

TR-105569 Proceedings (RP2414); $200
Contractor: Paul Williams and Associates
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24448

Dry Transfer System for Spent Fuel: Project Report

TR-105570 Final Report (RP3290-9); $50,000
Contractor: Transnuclear, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: R. Lambert
Fax ID: 24450

Evaluation of the Impact of Elevated Lithium Concentrations on Zircaloy-4 Fuel Clad Oxidation in the Millstone-3 PWR
TR-105662 Final Repor: (RP2493-5); $5000
Contractor: Nuclear Electric PLC
Business Unit: Nuclear Power
EPRI Project Manager: H. Ocken
Fax ID: 24575

Characterization of Carbon-14 Generated by the Nuclear Power Industry
TR-105715 Final Report (RP2724-4); $200
Contractors: Vance & Associates, Inc., J. E. Cline & Associates, Inc.; Battelle Pacific Northwest Laboratories
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook
Fax ID: 24657

An Environmental Factor Approach to Account for Reactor Water Effects in LWR Pressure Vessel and Piping Fatigue Evaluations
TR-105759 Final Report (WO3321-3); call for price
Contractor: GE Nuclear Energy
Business Unit: Nuclear Power
EPRI Project Manager: S. Gosselin
Fax ID: 24718

POWER DELIVERY

Distribution Engineering Workstation, Vols. 3–5
EL-7249-V3–V5 Final Report, license required
Contractors: BSG Alliance/IT, Inc.; Virginia Tech, College of Electrical Engineering
Business Unit: Distribution
EPRI Project Manager: H. Ng
Fax ID: 25029

Effect of DC Testing on Extruded Crosslinked Polyethylene Insulated Cables: Phase II
TR-101245-V2 Final Report (RP2436-1); $5000
Contractor: Detroit Edison Co.
Business Unit: Distribution
EPRI Project Manager: B. Bernstein
Fax ID: 24853

Bi-Directional Satellite Communications Terminal
TR-103577 Final Report (RP2949-12); $5000
Contractor: NovaNet Communications, Inc.
Business Unit: Distribution
EPRI Project Manager: W. Blair
Fax ID: 25229

Mutual Design: Overhead Transmission Lines and Railroad Facilities Susceptibility Program Phase II, Vols. 1–3
TR-103945 Final Report (RP1902-7); $5000
Contractors: BIRL/Northwestern University; Burg & Associates
Business Unit: Transmission
EPRI Project Manager: J. Hall
Fax ID: 21252

Magnetic Field Management for Overhead Transmission Lines: Potential Options for Low-Field Designs
TR-104413 (see listing under Environment)

Fielding a Real-Time Pricing Program: Pennsylvania Power & Light Case Study
TR-105042 Final Report (RP7802-1), $5000
Contractor: Christensen Associates
Business Unit: Utility Resource Planning & Management
EPRI Project Manager: C. Smyser
FaxID: 23646

Real-Time Pricing QuickStart Guide: Fielding Real-Time Pricing
TR-105045 Final Repor: (RP2801-4); $10,000
Contractor: Christensen Associates
Business Unit: Utility Resource Planning & Management
EPRI Project Manager: C. Smyser
Fax ID: 23653

Distribution Automation and Demand-Side Management Demonstration for Northern States Power
TR-105108 Final Report (RP3674-8, RP3807-1); $5000
Contractor: Northern States Power Co.
Business Unit: Distribution
EPRI Project Managers: W. Blair, L. Carmichael
Fax ID: 23752

Low Cost Radio Project
TR-105115 Final Repon (RP3759-1), $5000
Contractor: Southern California Edison Co.
Business Unit: Distribution
EPRI Project Manager: A. Sundaram
FaxID: 23765

Thyristor Controller Retrofit Studies for a Western Area Power Administration Phase-Shifting Transformer, Vols. 1 and 2
TR-105186-V1, TR-105186-V2 Final Report (RP3022-2); $5000
Contractors: Western Area Power Administration; General Electric Co.
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: D. Maratukulam
Fax ID: 23893

Control Center Advisor for Load Management (C^2ALM)
TR-105187 Final Report (RP2944-5, TC3708-4); license required
Contractor: TASC
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: R. Adapa
FaxID: 23895

Expert System for Power System Planning and Engineering (ESP): Transient Stability Input and Output Data Analysis
TR-105188 Final Report (RP3128-1), $5000
Contractor: ABB Power T&D Co.
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: R. Adapa
Fax ID: 23897

Adaptive Out-of-Step Relaying
TR-105195 Final Report (RP3022-10); $5000
Contractor: Virginia Tech, Center for Power Engineering
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: A. Edris
Fax ID: 23195

Summary of Transmission Line Structure Foundation Research
TR-105206 Final Report (RP1493-4); $5000
Contractor: Cornell University, Geotechnical Engineering Group
Business Unit: Transmission
EPRI Project Manager: A. Hirany
FaxID: 23932

Assessment of Voltage Security Methods and Tools
TR-105214 Final Report (RP3578-1); $5000
Contractor: B.C. Hydro
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: D. Maratukulam
Fax ID: 23942

Error Correction Methods for Measuring Harmonics in Power Systems
TR-105215 Final Repor: (RP3098-4); $5000
Contractor: Georgia Institute of Technology
Business Unit: Distribution
EPRI Project Manager: D. Richardson
Fax ID: 23944

Incorporating Detailed Dynamic Models in the Transient Energy Function (TEF) Method
TR-105259 Final Report (RP2206-6), $5000
Contractor: Georgia Institute of Technology, School of Electrical and Computer Engineering
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: P. Hirsch
Fax ID: 24014

Hourly Load Forecasting Using Artificial Neural Networks
TR-105278 Final Repor: (RP2473-44, RP3573-4); $5000
Contractor: Southern Methodist University
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: D. Maratukulam
Fax ID: 24047

Improved Ammoniacal Copper Carboxylate Wood Preservative
TR-105372 Final Report (RP1528-5), $5000
Contractor: Mississippi State University, Forest Products Laboratory
Business Unit: Distribution
EPRI Project Manager: H. Ng
Fax ID: 24181

Application of Taxonomy Theory, Vol. 1: Computing a Hopf Bifurcation-Related Segment of the Feasibility Boundary
TR-105492-V1 Final Report (RP3573-10), $5000
Contractor: Washington University (St. Louis)
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: P. Hirsch
Fax ID: 24333

Valuing Generation Assets in Uncertain Markets: An Introduction to Binomial Models
TR-105523 Final Report (RP4024), $10,000
Business Unit: Utility Resource Planning & Management
EPRI Project Manager: R. Goldberg
Fax ID: 24378

Effects of Intense Fluid Pumping on Forced-Cooled Cables
TR-105534 Final Report (RP7914-3); $5000
Contractor: Underground Systems, Inc.
Business Unit: Transmission
EPRI Project Manager: D. Von Dollen
Fax ID: 24401

Inter-Control Center Communications Protocol (ICCP): Interoperability Test, Version 5.1

TR-105552 Final Report (RP3355-7); $5000
Contractor: ECC, Inc.
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: D. Becker
Fax ID: 24423

Proceedings: Forum on Ancillary Services

TR-105686 Proceedings (RP4169); $200
Contractor: Zadeh Meyer Engineering, Inc.
Business Unit: Substations, System Operations & Storage
EPRI Project Manager: A. Vojdani
Fax ID: 24625

STRATEGIC R&D

Small Punch Testing for Fracture Toughness Measurement

TR-105130 Final Report (RP2426-38); $200
Contractor: Failure Analysis Associates, Inc.
Business Unit: Strategic R&D
EPRI Project Manager: V. Viswanathan
Fax ID: 23787

Small Punch Testing for Irradiation Embrittlement

TR-105131 Final Report (RP8046-3); $1000
Business Unit: Strategic R&D
EPRI Project Manager: V. Viswanathan
Fax ID: 23789

Development of Fiber Bragg Grating Sensors for Utility Applications

TR-105190 Final Report (RP8004-9); $200
Contractor: United Technologies Research Center
Business Unit: Strategic R&D
EPRI Project Manager: J. Weiss
Fax ID: 23902

Wellhead Deliverability of Natural Gas: Assembling the Evidence

TR-105405 Final Report (RP3201); $395
Contractor: Charles River Associates, Inc.
Business Units: Strategic R&D; Fossil Power Plants; Gas & New Coal Generation
EPRI Project Manager: J. Platt
Fax ID: 24231

The Emission Allowance Market and Electric Utility SO_2 Compliance in a Competitive and Uncertain Future

TR-105490 Final Report (RP3440-5); $495
Contractors: Keith D. White; Energy Ventures Analysis, Inc.; Van Horn Consulting
Business Units: Strategic R&D; Environmental & Health Sciences, Environmental Control; Fossil Power Plants
EPRI Project Manager: J. Platt
Fax ID: 24329

Wavelet Applications for Modeling in the Atmospheric Sciences: Current Status and Potential Extensions

TR-105691 Final Report (4CH3072); $200
Contractor: Envair
Business Unit: Strategic R&D
EPRI Project Managers: A. Hansen, M. Wildberger
Fax ID: 24621

EPRI Events

MAY

9–10
Strategic Asset Management for a Competitive Utility Environment
Atlanta, Georgia
Contact: Rich Goldberg, (415) 855-2397

13–14
Improving Building Systems in Hot and Humid Climates
Fort Worth, Texas
Contact: Mukesh Khattar, (415) 855-2699

22–24
1996 Heat Rate Improvement Conference
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

JUNE

2–7
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Amy Winn, (816) 235-5620

3–4
Motor Rewind Course
Atlanta, Georgia
Contact: Denise Wesalainen, (415) 855-2259

4–5
Repowering Workshop
Washington, D.C.
Contact: Christine Lillie, (415) 855-2010

4–6
EPRI Reactor Pressure Vessel Inspection Conference
Squaw Valley, California
Contact: Susan Otto, (704) 547-6072

10–13
Balance-of-Plant Heat Exchanger Workshop
Jackson Hole, Wyoming
Contact: Kenji Krzywosz, (704) 547-6096

11–13
Interaction of Non-Iron-Based Materials With Water and Steam
Piacenza, Italy
Contact: Michele Samoulides, (415) 855-2127

17–19
6th International ISA POWID/EPRI Controls and Instrumentation Conference
Baltimore, Maryland
Contact: Lori Adams, (415) 855-8763

25–27
Service Water Systems Reliability Improvement Seminar
Daytona Beach, California
Contact: Susan Otto, (704) 547-6072

JULY

22–24
1996 International Low-Level-Waste Conference
New Orleans, Louisiana
Contact: Michele Samoulides, (415) 855-2127

24–26
ASME/EPRI Radwaste Workshop
New Orleans, Louisiana
Contact: Michele Samoulides, (415) 855-2127

29–August 1
Fossil Plant Maintenance Conference
Baltimore, Maryland
Contact: Lori Adams, (415) 855-8763

AUGUST

4–8
4th International Conference on Mercury as a Global Pollutant
Hamburg, Germany
Contact: Don Porcella, (415) 855-2723

5–7
Turbine Generator Operation
Redondo Beach, California
Contact: Denise Wesalainen, (415) 855-2259

6–9
Workshop on NO_x Controls for Utility Boilers
Cincinnati, Ohio
Contact: Susan Bisetti, (415) 855-7919

7–9
International Conference on Sustainable Thermal Energy Storage
Chicago, Illinois
Contact: Beverly Speer, (608) 262-8220

11–16
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Amy Winn, (816) 235-5620

18–23
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Amy Winn, (816) 235-5620

26–30
Condenser Technology Seminar and Conference
Boston, Massachusetts
Contact: Lori Adams, (415) 855-8763

SEPTEMBER

3–4
Nuclear Plant Performance Improvement
Asheville, North Carolina
Contact: Susan Otto, (704) 547-6072

OCTOBER

1–4
New Power Generation Technology
San Francisco, California
Contact: Michele Samoulides, (415) 855-2127

3–4
Decision Analysis for Environmental Risk Management
Palo Alto, California
Contact: Robert Goldstein, (415) 855-2593

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