EPRI JOURNAL

JANUARY/FEBRUARY 1998

Digital Revolution

Milestones of 25 Years

Global Sustainability

Technologies for Tomorrow

Celebrating the Past Powering the Future

A Special 25th Anniversary Issue

About EPRI

Electricity is increasingly recognized as a key to societal progress throughout the world, driving economic prosperity and improving the quality of life. EPRI delivers the science and technology to make the generation, delivery, and use of electricity affordable, efficient, and environmentally sound.

Created by the nation's electric utilities in 1973, EPRI is one of America's oldest and largest research consortia, with some 700 members and an annual budget of about $500 million. Linked to a global network of technical specialists, EPRI scientists and engineers develop innovative solutions to the world's toughest energy problems while expanding the opportunities for a dynamic industry.

EPRI. Powering Progress

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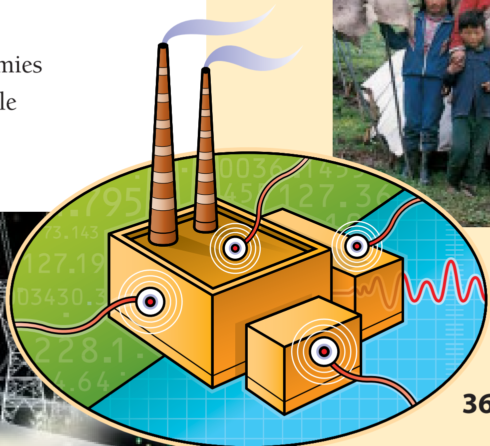
EDITORIAL

FEATURES



Cover art by James William Gary

EPRI at 25: A Commitment to the Future

EPRI WAS BORN OF CRISIS—a crisis of both confidence and capability. The great northeastern blackout of 1965 revealed for the first time serious vulnerabilities in the nation's electricity supply system. War in the Mideast in 1967 foreshadowed the energy crises of the 1970s and the danger inherent in our growing dependence on foreign oil. And the National Environmental Policy Act of 1969 kicked off decades of environmental legislation that would challenge utilities' scientific and technical capabilities. The convergence of these and related issues called into serious question the ability of the existing energy infrastructure to effectively serve the needs of the nation.

The creation of organizations like the Electric Research Council (ERC) and the North American Electric Reliability Council was, of course, a key step in dealing with these pressing issues. But the real problem was that the utility business was substantially underinvested in the science and technology required to adapt to changing needs. Individual utilities had neither the resources nor the breadth of expertise to deal with all the technical difficulties that were coming to a head. And even as the ERC formulated its incisive and farseeing research plan for the industry, the lack of an effective, securely funded organization to carry out the work itself was obvious. Threatened by Senate proposals in 1971 to create a federal agency to conduct electricity-related R&D, the nation's public and private utilities banded together to develop an industry-organized alternative—the Electric Power Research Institute, now known simply as EPRI.

Under the leadership of founding president Chauncey Starr, EPRI opened its doors in 1973, taking over R&D projects previously managed by the ERC and the Edison Electric Institute and quickly expanding its work to cover the industry's most urgent and difficult issues. Chauncey's extraordinary vision of how these problems could best be approached—through central management of collaboratively funded research activity—was both tremendously effective and far ahead of its time. Over the past quarter century, first under Chauncey and subsequently under the solid leadership of Floyd Culler and Dick Balzhiser, EPRI has grown to be the industry's most versatile and valuable technical resource. Its scientific and technical achievements, some of which are highlighted in this special issue of the *Journal,* have returned benefits to utilities and their customers conservatively estimated at over $50 billion—nearly 10 times the collective utility investment in EPRI.

Today the power industry is undergoing change far more profound than at the time of EPRI's creation. But despite the huge uncertainties and dislocations associated with industry restructuring, to my mind the mode of change is not crisis but rapid evolution, fueled by innovation and directed by opportunity. No factor will be more important in this evolution than technology. Technology will provide the greater efficiency and enhanced capabilities that companies will need to compete effectively in an increasingly deregulated business environment. Technology will provide the communications and control systems required by the industry's new infrastructures for power sales and delivery. And, most exciting for the energy customer, technology will redefine the very products, services, and markets on which the new competitive energy business will be based.

Beyond these immediate business concerns, the stakes are even higher. Because it is an unparalleled enabling technology, electricity plays a unique and critical role in powering innovation and growth in our economy and our society. Electricity is indeed the prime mover and mega-infrastructure that has powered progress in the century now ending, and it will be even more important in the century to come. The technological underpinnings have already been established for truly revolutionary advances. Microprocessors are projected to become so powerful and inexpensive that they will allow the automation of virtually all the routine functions of daily life, commerce, and industry. Advanced electrotechnologies are bringing a new standard of precision and efficiency to industrial processes, from electrochemical synthesis to plasma- and laser-based materials processing. Electrically driven supersonic magnetic levitation trains are envisioned that could carry 10,000 passengers between cities 2000 kilometers apart in less than an hour.

The opportunities are just as exciting for the power infrastructure. Superconducting cables and storage units, coupled with power electronic controllers for transmission and distribution systems and smart meters at the customer site, add up to a revolution in power delivery—a revolution that will be needed to meet the demands of a new digital, knowledge-based economy. Such cutting-edge infrastructure sets the stage for the creation of a truly continental power grid, which will both be augmented by and facilitate a growing array of stationary and mobile distributed generation options—fuel cells, microturbines, and photovoltaics, to name only a few. In fact, shirt-button-size gas turbine–generator modules are being designed that could form the basis for compact personal energy systems to conveniently power portable computing, communications, and entertainment devices.

Advances like these—based on the exquisitely flexible and powerful synergy between electrification and technological innovation—are quickly moving from the realm of science fiction into our daily lives. If we can encourage further technology development and investment by and through a restructured power industry, the public benefits for the nation over just the next 25 years could be profound. It is possible, for example, that our national energy efficiency could be improved by 20% and that a net trillion dollars could be added to the gross domestic product each year. And still more important are the opportunities in the global sphere, where about 2 billion people—over 40% of the world's population—live in poverty and deprivation, lacking access to electricity and the most basic benefits it affords.

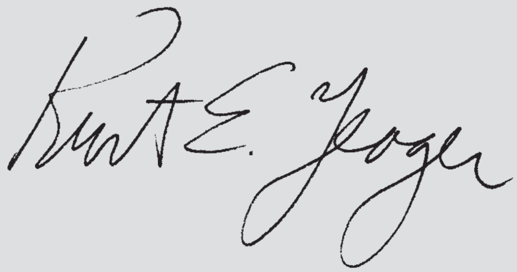
As the new millennium approaches, we are taking steps to ensure that EPRI's value to the evolving industry remains indispensable and that electricity's enabling power is brought to its fullest potential for the broadest reach of business and society. While our core values are unchanged, we have adopted a new business model that is more responsive to the needs of our members and more relevant to a competitive environment. We are reaching out to the new players in the growing energy enterprise, both to solicit their support and to involve them in the rich collaborative process that has so successfully leveraged technical innovation in the past.

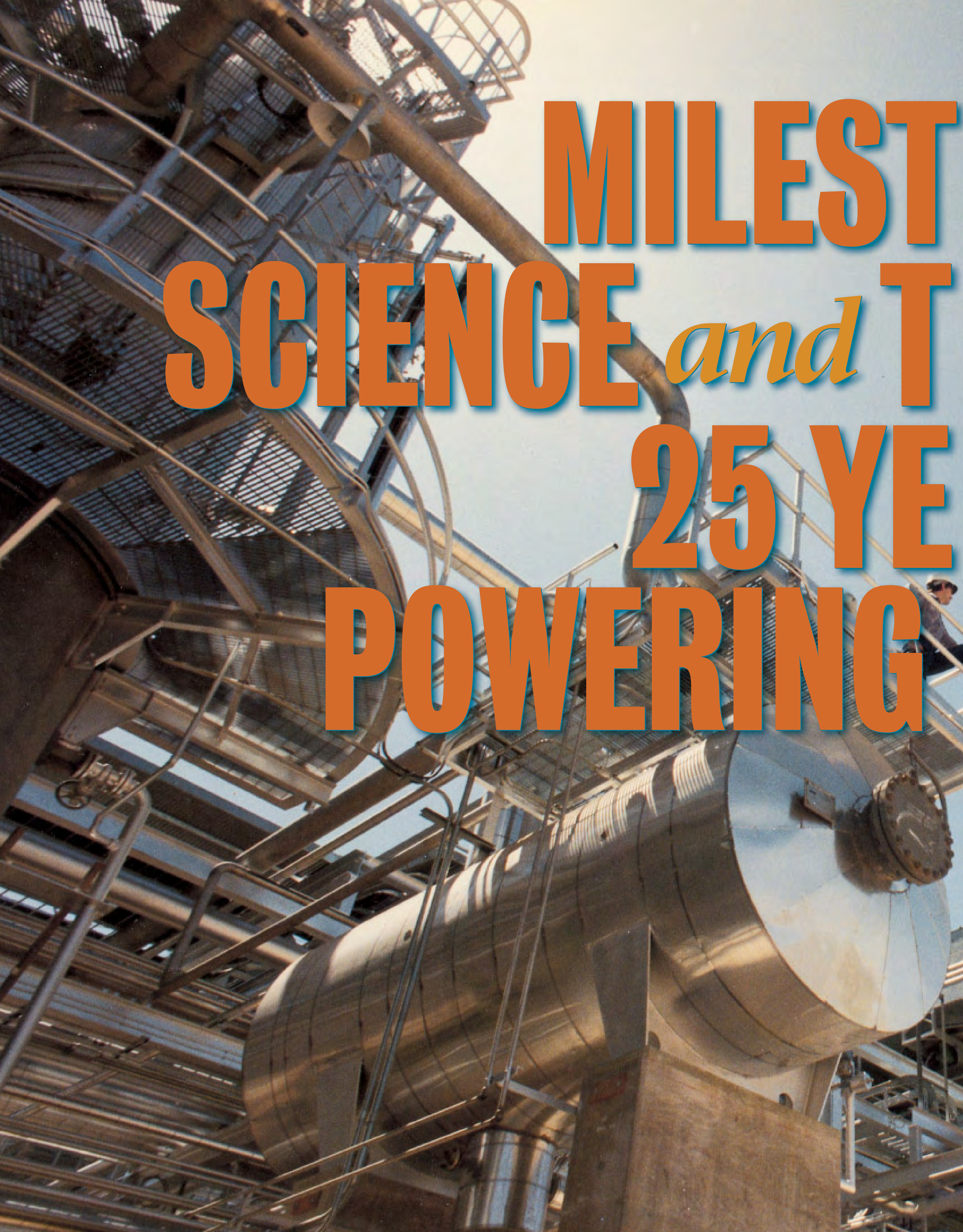
Certainly EPRI will continue to provide the science and technology that power providers will need to prosper in the difficult times ahead. To this end, we will develop solutions to problems, increase technical capabilities, and open up new business opportunities. But if we are truly to lead, we must do much more than this, progressing beyond adaptation to actually help steer the direction of change. EPRI took a key step in this effort last year by launching the Electricity Technology Roadmap initiative, a highly collaborative project to strategically guide energy R&D over the coming decades. Specifically, the goal is to develop a consensus among the diverse stakeholders in the global energy enterprise on how best to focus limited R&D resources to achieve maximum stakeholder and societal value.

While electricity is a unique enabler of societal progress, such progress is not automatic: it requires gathering the best ideas we can find and committing ourselves to the development of the science and technology that will bring them to fruition. The roadmap initiative will facilitate this goal by providing a framework to guide technological progress toward the destinations most important to the world's increasingly interdependent societies—destinations that include economic prosperity, environmental protection, quality of life, and sustainable global development. The roles electricity can play in helping us arrive at those destinations will be identified, along with the critical scientific and technical gaps that must be bridged by specific R&D initiatives.

In a very real way, the roadmap will define what we should become—as businesses, as energy providers, and as responsible members of the global community. EPRI begins its second quarter century of service with a renewed sense of purpose and a dedication to making this future happen. Working together in support of these goals is the most important work we as an industry can do to take firm charge of our technical destiny and build an enduring, innovative energy foundation for future generations.

Kurt E. Yeager
President and Chief Executive Officer





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SCIENCE *and* T
25 YE
POWERING

ONES *of* ECHNOLOGY: ARS *of* PROGRESS

EPRI'S QUARTER CENTURY OF WORK on behalf of the utility industry and its customers is unique in many respects. The breadth of its technical program, certainly, is unmatched by any other such organization in the world. EPRI's reputation for quality and credibility has allowed it to attract the interest, ideas, and talents of the world's preeminent technical experts and organizations, leading to strong solution-development teams and alliances that cut across the full spectrum of business, industry, and government. And EPRI's collaborative funding framework has ensured that its results deliver value far beyond the dollars invested by individual members. Together these advantages have led to a great many accomplishments, a selection of which are chronicled in the following pages.

1973

• EPRI takes over the management of 55 research projects from the Edison Electric Institute and the Electric Research Council and specifies goals for 90 additional projects.

1974

• Staffing is increased to include 115 top energy experts. Half of EPRI's research funding is allocated to near-term objectives, 40% to intermediate-term projects, and 10% to long-term research.

UHV transmission system

• EPRI issues its first project reports, dealing with ultrahigh-voltage systems, underground transmission, coal gasification and beneficiation, and nuclear plant design, safety, operation, and maintenance.

1975

• EPRI completes its 150th research project.

• At the request of the National Association of Regulatory Utility Commissioners (NARUC), EPRI begins work on the Electric Utility Rate Design Study, carried out in coopera-

RON MAY

Rate Design Study

tion with the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association. Over its nine-year life, the study establishes the technical feasibility and societal costs and benefits of time-differentiated rates and assists utilities and regulators in the practical application of ratemaking concepts.

• EPRI launches its electric field research with a three-year study of the potential biological effects of fields produced by transmission lines and substations. Over the next two decades, EPRI develops and manages the world's largest private research program on electric and magnetic fields.

Electric field research

• A memorandum of understanding with the National Bureau of Standards establishes guidelines for sharing information on measurement technologies related to electric power equipment and systems.

Measurement standards

1976

Six Cities Study

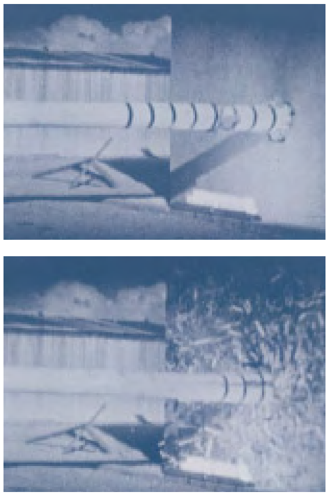
• EPRI joins with the National Institute of Environmental Health Sciences to sponsor the country's largest epidemiological study of air pollution health effects—the Six Cities Study, performed by the Harvard School of Public Health.

• The Emissions Control and Test Facility is built alongside Public Service Company of Colorado's coal-fired Arapahoe station to test new environmental control equipment with actual plant exhaust gas streams.

RON MAY

Arapahoe test facility

• Full-scale tests with rocket-launched projectiles demonstrate that the containment walls of nuclear plants are structurally safe from tornado debris driven at improbably high speeds.



Tornado impact tests

• EPRI establishes the Energy Modeling Forum at Stanford University to improve the accuracy and capabilities of large energy-economic models through the study of specific supply, demand, and distribution issues.

1977

• The Steam Generator Owners Group is organized to study corrosion and other factors that limit the performance and availability of PWR steam generators. Research over the next decade pinpoints a series of root causes of this corrosion and develops a range of solutions.

Residential solar design

• Researchers develop a computer program for determining the most practical residential solar heating and cooling technologies for specific utility service areas.

• The refinement of key power train components—advanced gasifiers, gas turbines, and integration and control systems—clears the way for field testing of gasification–combined-cycle plant concepts.

• Research is initiated to quantify the effects of acid deposition on surface waters by analyzing biogeochemical processes in three Adirondack lake watersheds.

1978

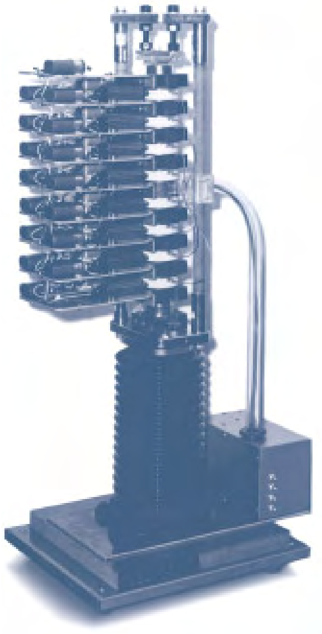
• EPRI's electric vehicle program begins with a two-year fleet van demonstration effort carried out in cooperation with Southern California Edison and the Tennessee Valley Authority.

RON MAY

Fleet van demonstration

• Rocket-sled tests demonstrate that reinforced-concrete nuclear reactor containment buildings would be little damaged by high-energy rotor fragments from a catastrophic steam turbine failure.

• A static VAR generator made up of thyristor-controlled capacitor banks is manufactured by Westinghouse with funding from EPRI and Minnesota Power.



Static VAR generator

1979

• The BWR Owners Group is set up with support from 24 nuclear utilities to develop solutions to growing problems with intergranular stress corrosion cracking in recirculation piping systems. By the middle of the 1980s, EPRI-developed remedies have reduced IGSCC-related capacity losses by a factor of 10.

• The successful field testing of a 1-MW Brayton-cycle solar receiver developed by EPRI, DOE, and Boeing Engineering & Construction clears the way for the development of a commercial-size central-receiver solar power demonstration plant.

1-MW solar receiver

• EPRI and Allied Chemical develop a technology for manufacturing amorphous metal alloy strip, whose lack of crystalline structure promises to cut electrical losses by 70% in transformer core applications.

Amorphous metal production

EPRI establishes the Nuclear Safety Analysis Center (NSAC) to make a detailed analysis of the Three Mile Island accident and to develop recommendations for improvements in nuclear plant safety.

• At the industry's request, EPRI designs the organizational framework for the Institute of Nuclear Power Operations. INPO is set up as an independent organization to promote human factors engineering, enhance operator training and evaluation, and coordinate nuclear emergency preparedness.

1980

• The Nondestructive Evaluation Center begins operation near Charlotte, North Carolina. The world's only such facility, the NDE Center provides capabilities for demonstrating new NDE technologies on full-size plant components and for training engineers and technicians in their use.

RON MAY

NDE training

• EPRI and SRI International develop an airborne laser-based lidar (light detection and ranging) system for measuring and mapping the movement of power plant stack plumes in real time.

• Two large-scale coal liquefaction pilot plants begin operation to demonstrate the H-Coal and Exxon Donor Solvent processes as economical and environmentally acceptable ways of producing substitutes for petroleum-derived fuels. Both pilot plants produce satisfactory "crude oil" from a number of feed coals by 1982.

H-Coal pilot plant

• A geothermal rotary separator–turbine is developed and tested that captures process energy lost with the residual water in direct flash-to-steam geothermal processes. The RST allows the tapping of moderate- to high-temperature geothermal resources at a cost competitive with some conventional generating options.

RST development

● The Battery Energy Storage Test (BEST) Facility is dedicated in New Jersey, under the joint sponsorship of EPRI, DOE, and Public Service Electric and Gas. It is the first facility in the world capable of evaluating storage batteries on the megawatt scale needed for utility system load leveling.

RON MAY

BEST Facility

1981

● INPO takes over the direction and funding of NSAC's Notepad telecommunications system, set up immediately after the Three Mile Island accident to provide utilities with continuous updates on safety issues at nuclear plants.

● The Sulfate Regional Experiment—a comprehensive program designed to identify the sources, concentrations, and

SURE monitoring

transport characteristics of sulfates and other air pollutants in the northeastern United States—is completed. Integrating data from 54 ground monitoring stations and five instrumented aircraft, SURE sets the standard for regional air quality studies.

● EPRI and DOE develop preliminary designs for a utility-scale compressed-air energy storage plant and conclude that CAES is an economically feasible storage technology for serving daily load peaks.

● EPRI develops Minac, a remotely controlled radiographic inspection tool small enough to be positioned inside a reactor coolant pump to perform X-ray examination of the pump welds.

Minac inspection tool

● The Coal Cleaning Test Facility begins operation at Pennsylvania Electric's Homer City power station. The facility is the nation's foremost resource for developing advanced coal-cleaning techniques and assessing the effects of coal quality on boiler reliability and efficiency.

1982

● The PWR Safety and Relief Valve Test Program is completed after full-scale valve testing at facilities in North Carolina, California, and Connecticut. Prompted by the NRC's post–Three Mile Island requirements, the program establishes the operability of ex-

COURTESY WYLE LABORATORIES

Relief valve test

isting valve designs under the full range of plant conditions.

● EPRI's Utility Acid Precipitation Study Program establishes a network of 20 acid rain monitoring stations in the eastern United States.

● The widely influential Over/Under Capacity Planning Model is released. The model is the first to explicitly consider electricity demand uncertainty in estimating the costs and benefits to utilities and consumers of various levels of capacity expansion.

● The Transmission Line Mechanical Research Facility, the world's most advanced center for transmission system structural research, begins operation in Haslet, Texas. Tests-to-failure of full-scale transmission towers, poles, and foundations are used to improve structural modeling techniques and to identify the most reliable, lowest-cost designs.

RON MAY

Full-scale tower testing

1983

● EPRI develops the Chlor-N-Oil screening kit—a pocket-size, disposable test kit for the on-site detection of polychlorinated biphenyls in transformer oil. By the late 1990s, the inexpensive test has saved the utility industry over $140 million in laboratory analysis costs for compliance with PCB disposal regulations.

RON MAY

Chlor-N-Oil kit

● In a project cosponsored with General Electric, EPRI designs and tests a prototype high-reliability gas turbine combustion system employing a multinozzle combustor and an impingement-cooled transition piece.

The advanced design elements are built into GE's groundbreaking 7F turbine series.

• EPRI licenses its patented Polysil polymer concrete to nine companies for the manufacture of cast-molded, nontracking electrical insulators. This rugged replacement for conventional porcelain insulators wins a coveted R&D 100 Award from *R&D Magazine* as one of the 100 most significant technical products of the year.

Polysil insulator

• The Electric Generation Expansion Analysis System computer program is released to help utilities plan future generation systems under more-complicated regulations and uncertain load growth. EGEAS calculates what plants will be needed, develops project schedules, and identifies lowest-cost plant alternatives.

1984

• EPRI launches its electrotechnology program with the establishment of the Center for Materials Fabrication at Battelle Columbus Laboratories. The new center focuses on improving industrial productivity through the development and promotion of efficient electricity-based processes and equipment.

The 100-MW Cool Water integrated gasification–combined-cycle plant goes on-line—the cleanest coal-fueled power plant ever built. This pioneering commercial-scale demonstration of IGCC technology is led by EPRI, with major participation by Southern California Edison, General Electric, Bechtel Power, and Texaco.

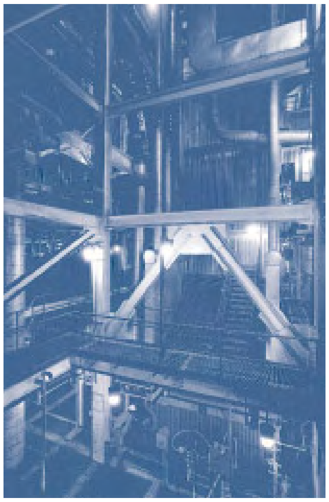
RON MAY

• The five-year Integrated Lake-Watershed Acidification Study (ILWAS) culminates with the development of a computer model that comprehensively simulates the movement of water through a lake watershed, quantifies the processes that can alter watershed acidity, and calculates the rate of potential acidification.

ILWAS monitoring

• Northern States Power's Monticello plant becomes the first operating nuclear plant to apply EPRI's LOMI chemical decontamination process. LOMI, which dissolves and flushes radioactive corrosion films from a plant's recirculation piping, is used in 90% of all U.S. decontamination projects carried out since 1986.

• Work begins on three utility-scale fluidized-bed combustion demonstration projects, hosted by Northern States Power, Colorado-Ute Electric, and the Tennessee Valley Authority. The demonstrations, all in operation by 1988, provide the technical basis for utility application of this clean coal generation option.



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FBC demonstration

1985

• At the request of NARUC and in cooperation with the North American Electric Reliability Council (NERC), EPRI begins a scoping study on transmission access to identify the technical impediments to such access and explore ways of increasing transmission capability.

• The EPRI-sponsored Heber binary-cycle geothermal demonstration plant is put into service in California's Imperial Valley. Heber is designed to operate on moderate-temperature geothermal brines, which are at least 50 times more common than the dry-steam geothermal resources tapped up to this time.

RON MAY

Heber geothermal plant

• EPRI's second electrotechnology center—the Center for Materials Production—is established in Pittsburgh to conduct research on more-efficient methods for producing steel and other primary metals.

• Working in cooperation with the NRC and the nation's reactor manufacturers, EPRI initiates the Advanced Light Water

Reactor Program. The goal is to produce detailed requirements and designs for simplified, standardized LWRs that are less costly and inherently safer than the existing generation of plants.

• EPRI launches the largest privately funded acid deposition study in the United States, with cofunding from Empire State Electric Energy Research Corporation (ESEERCO) and the New York State Energy Research and Development Authority (NYSERDA).

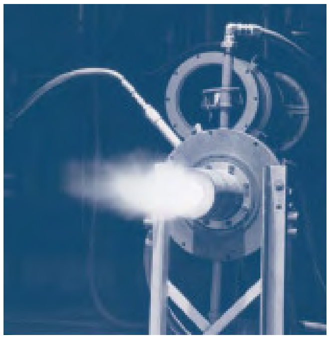
RON MAY

Acid deposition monitoring

1986

• EPRI develops an analytical method for reassessing seismic safety margins at nuclear power plants in light of revised hazard estimates for the eastern United States. In 1988, the NRC accepts the use of this method to meet regulatory requirements.

• Low-loss amorphous-core distribution transformers are commercialized from material and process work pioneered by EPRI and Allied Chemical. Since 1990, the aggregated national energy savings from the use of these advanced transformers have amounted to more than $50 million a year.



Electric plasma torch

• An electric plasma torch for remelting scrap iron is demonstrated at industrial scale. Operating at temperatures far exceeding those obtainable by burning fossil fuel, the torch can cut the cost of remelted and purified scrap steel by 10–30%.

EPRI-funded research at Stanford University produces a breakthrough in photovoltaics with the development of the point-contact solar cell. The concentrating silicon-based cell attains a sunlight-to-electricity conversion efficiency of 28% in the laboratory—the highest efficiency ever for a photovoltaic device and within a few percentage points of the theoretical limit for a silicon-only device.

• The Power Electronics Applications Center is established in Knoxville, Tennessee, to develop and promote power electronics technology for wide industrial, commercial, and residential application.

• EPRI research demonstrates that fly ash, sludge, and other high-volume utility wastes should retain their nonhazardous classification under proposed federal toxicity testing procedures. The EPA, relying heavily on the EPRI data, subsequently agrees in its final ruling, saving the utility industry billions of dollars in waste handling and disposal costs.

1987

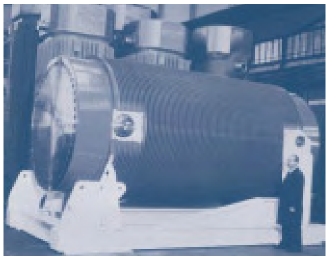
• EPRI develops EMDEX—the first lightweight, portable monitoring device that is capable of recording real-time data on personal exposure to electric and magnetic fields. Originally used in EPRI's EMF research, the device is commercialized for broader application in 1989.

RON MAY

EMDEX EMF monitor

• The first full-size turbine rotor forgings are produced from an EPRI-developed superclean steel. This high-purity alloy features reduced temper embrittlement and improved fracture toughness, creep, and fatigue properties.

• NOREM iron-based hardfacing alloys are developed as a substitute for cobalt materials in nuclear plant valves. Their use substantially reduces radiation buildup in recirculation piping systems from cobalt-60.



Spent-fuel cask

• Tests of metal casks and steel-lined concrete containers are performed at two utilities to demonstrate inexpensive, on-site storage of dry spent nuclear fuel—a key utility need in light of delays in the federal permanent-repository program.

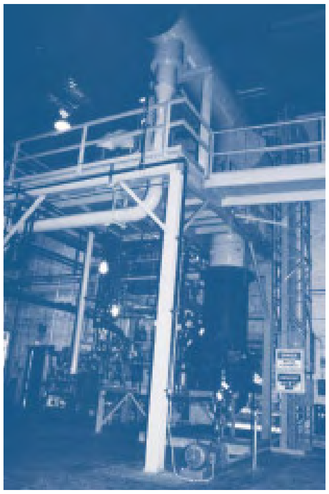
• EPRI and General Electric develop a rotor crack detector that gives early warning of cracking in a steam turbine shaft while the turbine is operating. Using a microcomputer and specialized software, the detector senses subtle changes in vibration patterns when a crack begins to form.

1988

• Under EPRI's electrotechnology program, a pilot facility for curing automobile coatings with infrared radiation is installed at a Chrysler manufacturing plant, offering opportunities to reduce floor space, improve finish quality, and eliminate solvent emissions without affecting productivity.


Infrared paint curing

• The first full-scale plasma-fired cupola to convert steel scrap into iron begins operation at the General Motors foundry in Defiance, Ohio. The EPRI-developed technology reduces production costs by 30% in the first year.


Plasma-fired cupola

• EPRI publishes the *Distribution Cable Research Digest,* which consolidates more than 20 years of work on failure modes, manufacturing techniques, and diagnostics for underground distribution cable. The digest makes it possible to confidently specify solid-dielectric cables with 30- to 40-year lifetimes.

• General Electric begins the commercial production of an advanced gate-turnoff thyristor developed through EPRI research. Initial applications are focused on improving the energy efficiency of variable-speed drives for large motors.

• EPRI develops the GEZIP chemical passivation process for reducing the buildup of radioactive cobalt in BWR primary cooling systems. Feedwater injection of soluble zinc allows only a thin layer of oxide film to adhere to the stainless steel piping, thus limiting the sites for cobalt incorporation.

1989

• The world's first high-voltage fuel cell stack to use advanced molten carbonate technology begins operation in Danbury, Connecticut, converting natural gas directly into electricity at high efficiency.

• The Coal Cleaning Development Center is spun off as CQ Inc., EPRI's first for-profit subsidiary. CQ Inc. is able to promote greater investments in coal quality R&D because, as an independent organization, it can attract a broader range of clients, including coal companies, equipment manufacturers, and government agencies.


CQ Inc.


G-Van fleet vehicle

• The EPRI-funded G-Van, a full-size fleet vehicle based on the General Motors line, becomes the first electric vehicle to meet all major federal motor vehicle safety standards. Twenty-five prototype vehicles from the first production run begin field testing in utility fleets.

• The EPRI-developed HydroTech 2000 heat pump, offering integrated space and water heating, is introduced to the commercial market by Carrier Corporation. Over 30% more efficient than conventional electric heat pumps, the HydroTech 2000 permanently raises the bar for heat pump efficiency and catalyzes all manufacturers to push for similar energy-saving goals.

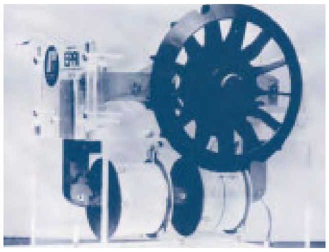
High-efficiency heat pump

• The world's first microprocessor-controlled predictive maintenance system is demonstrated at Philadelphia Electric's Eddystone unit 2. Electronic sensors and monitoring subsystems track the performance of every major plant component, sending a constant stream of information to diagnostic display terminals via a fiber-optic data highway.


RON MAY

Eddystone diagnostic displays

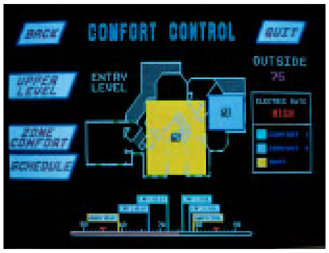
• In a cooperative effort with Argonne National Laboratory and Reliance Electric, EPRI produces and tests the world's first high-temperature superconducting motor—a 10-W direct-current machine made with experimental HTSC wire.


HTSC motor

1990

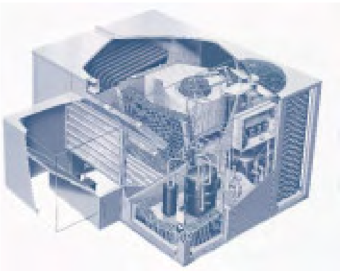
• The Advanced Light Water Reactor Utility Requirements Document, which defines the technical and economic goals for next-generation nuclear power plants, is completed and submitted to the NRC. The URD specifications are incorporated into General Electric's advanced BWR design, selected in 1996 by Taiwan Power for two new plants.

• Construction of the Electric Smart House is completed in Atlanta. Developed with the



Smart House control panel

National Association of Home Builders, this all-electric house showcases efficient, programmable appliances, advanced air conditioning and water heating equipment, and an integrated, microprocessor-controlled automation and energy management system.

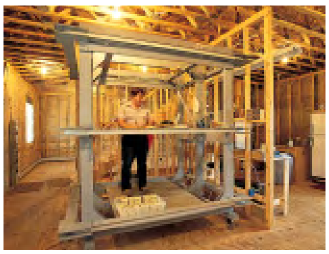


COURTESY LENNOX INDUSTRIES

Dual-fuel heat pump

- The EPRI-Lennox dual-fuel heat pump is commercialized as a replacement for conventional gas units. Combining an electric heat pump (for high efficiency) and a gas furnace (for supplemental heating) in a single package opens a new market for electric heat pump technology in harsh northern climates.

- Research and utility personnel training begin at EPRI's Magnetic Field Research Facility in Lenox, Massachusetts.



RON MAY

Magnetic field research

The facility features a simulated residential environment that can be electrically reconfigured to produce a wide variety of currents and magnetic fields for exposure and measurement studies.

The Utility Communications Architecture is released, establishing industrywide specifications for interconnectivity and communications. UCA enables utilities to integrate a wide variety of power system data and increases capabilities for such functions as transmission and distribution automation, two-way customer-utility communications, and automated meter reading.

1991

- **EPRI signs a participation agreement with the U.S. Advanced Battery Consortium—a collaborative R&D venture involving DOE and the Big Three U.S. automakers—to develop advanced battery technologies for electric vehicles. The agreement allows electric utilities, through their membership in EPRI, to work closely with the consortium.**

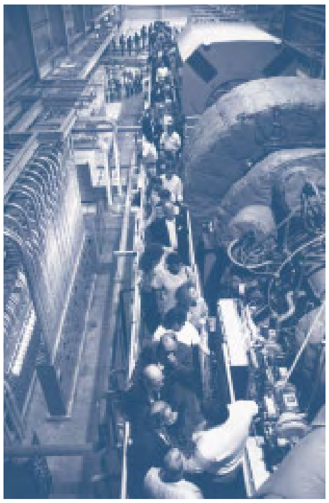
- The EPRI-funded Field Star 1000 magnetic field recorder becomes commercially available. This first-of-its-kind field survey instrument can generate maps of magnetic field flux density both outdoors and inside buildings.

RON MAY

Field Star 1000 recorder

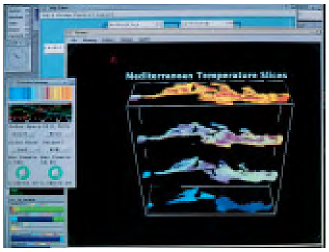
- EPRI introduces LightCAD, a software-based planning tool that makes it easier for architects and engineers to incorporate energy-efficient lighting in commercial buildings.

- The first U.S. compressed-air energy storage plant—a 110-MW, 26-hour unit—goes on-line at Alabama Electric Cooperative. The CAES unit, developed and built with EPRI's help, allows the cooperative to "bank" inexpensive nighttime generation for use during peak periods.



AEC's CAES plant

- EPRI joins forces with industry, government, and academic groups from the United States, Japan, Italy, and the Netherlands to form the Model Evaluation Consortium for Climate Assessment. The consortium's goal is to improve global climate simulation models in order to better anticipate the potential effects of greenhouse gas emissions.



RON MAY

Climate simulation model

1992

- EPRI's State-of-the-Art Power Plant WorkStation is released, along with the first 19 SOAPP technology modules. The software enables utility planners and engineers to compare a wide variety of available fossil plant components in terms of performance, size, and costs, and it can automatically generate preliminary preferred plant designs.

- ELOMIX, an innovative ion-exchange technique for continuously removing radioactive elements from nuclear plant decontamination solutions, is developed and tested. The technique substantially reduces the volume of radioactive waste that must be disposed of after decontamination procedures.

- Researchers pioneer superclean sample collection and analysis techniques as part of EPRI's Mercury Cycling Model

Superclean sample collection

development work. The model, which computes the formation of methylmercury in lakes and its bioaccumulation in the aquatic food chain, sets a new standard for studies involving trace elements in the environment.

● Terrasight—a portable, battery-operated device for detecting PCB and mineral oil spills—is commercialized. By allowing field personnel to reliably outline the extent of a spill, Terrasight substantially reduces the need for expensive, time-consuming laboratory analysis of soil samples.

RON MAY

Terrasight spill detector

● The National Lightning Detection Network, developed by EPRI and the State University of New York at Albany, is expanded to provide real-time information on lightning storm activity across the continental United States, enabling utilities to better manage repair crews and to reduce the duration of outages. The NLDN is subsequently commercialized with Global Atmospherics.

EPRI completes a landmark residential magnetic field measurement study—a comprehensive survey of the sources and strengths of magnetic fields in 1000 homes across the nation. The study produces a definitive database that serves as a valuable resource for designing field management strategies.

1993

● EPRI's Continuous Emissions Monitoring (CEM) Reporting Workstation is delivered for utility use. The workstation is designed to help utilities organize and submit the more than 600,000 emissions data points required by new EPA regulations for each power plant each year.

● An Indiana metal foundry installs EPRI's Sandsaver 2001, which uses infrared-heating and fluidized-bed technologies to clean sand that has been used for metal casting. The reclamation process saves the company $3 million and 1.4 million cubic feet of landfill space annually.

● EPRI releases its CHECWORKS program, a unique software tool to help nuclear and fossil plant operators control flow-accelerated corrosion and prioritize inspections. CHECWORKS can predict the rate of wall thinning and the time that will elapse before a given component must be repaired or replaced.

● The world's first power electronics–controlled, variable-speed wind turbine is commercialized through a partnership of EPRI, Kenetech/U.S. Windpower, Pacific Gas and Electric, and Niagara Mohawk. The advanced turbine's ability to operate at relatively low wind speeds vastly expands the regions where wind power can compete with fossil fuel generation. By 1997, the majority of wind machines manufactured in this country are based on this technology.

COURTESY U.S. WINDPOWER

Variable-speed wind turbine

● The SureSine active power line conditioner, developed with support from EPRI and Public Service Electric and Gas, is offered commercially by Westinghouse. The SureSine unit is the first integrated electronics package to combine adaptive, active harmonic filtering with sag compensation and instantaneous line voltage regulation.

SureSine line conditioner

1994

Soft Trencher

● The Soft Trencher excavation machine is developed by EPRI, Battelle Memorial Institute, and Concept Engineering Group. Using air jets and a vacuum airstream to break up and remove soil during trenching operations, the machine poses far less risk of damage to buried electrical cables and gas lines than hard-cutting equipment.

• EPRI research demonstrates that several environmentally preferred hydrofluorocarbon refrigerants and coolant mixtures can match the heat transfer properties of chlorine-based refrigerants, whose production is scheduled to be banned because of concerns about stratospheric ozone depletion. The assessment work helps manufacturers decide which sets of refrigerants to incorporate in new equipment.

Allegheny Power System retrofits two coal-fired units with the Low-NO_x Cell Burner—the first technology in DOE's Clean Coal Technology demonstration program to receive a commercial order. The advanced burner, developed by EPRI and Babcock & Wilcox, cuts emissions of nitrogen oxides by 50%.

COURTESY BABCOCK & WILCOX CO.

• EPRI's groundbreaking microwave clothes dryer is developed, and prototypes are demonstrated by 10 utilities. Because the dryer heats water molecules and not the clothes themselves, it is faster, more energy-efficient, and gentler on clothes than conventional dryers. The dryer wins the grand prize for home technology in *Popular Science*'s Best of What's New awards.

COURTESY NIAGARA MOHAWK POWER CORP.

Microwave clothes dryer

1995

• EPRI and Westinghouse announce the formation of Sure-Tech LLC, a business alliance to develop and commercialize advanced power electronics technologies for high-power applications, including transmission and distribution controllers.

• EPRI's Transmission Services Costing Framework is released to utilities, helping them define specific elements of unbundled transmission services, assign realistic costs to these elements, and develop an overall costing strategy to respond to new Federal Energy Regulatory Commission (FERC) rules on open-access tariffs.

• FERC asks EPRI and NERC to head up an effort to design a nationwide real-time information network for the posting of transmission service information. The network is developed on schedule after 18 months of intensive work.

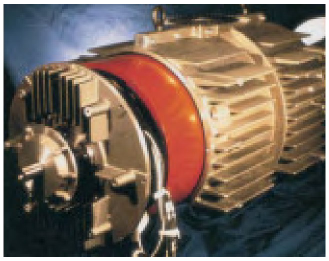
• EPRI and Maynard Steel Casting develop the world's first direct-current plasma ladle refiner to produce commercial grades of cast steel with very low levels of sulfur and oxygen. In addition to improving casting quality, the refiner increases the productivity of melting operations by up to 30%.

COURTESY WISCONSIN ELECTRIC POWER CO.

Plasma ladle refiner

• On the strength of EPRI tests showing that the coburning of manufactured gas plant waste in utility coal-fired boilers poses no significant harm to the environment, the EPA gives final approval for the process. The coburning strategy is expected to save the industry over $3 billion in MGP waste treatment costs.

• The Written-Pole motor becomes commercially available for single-phase remote applications of up to 60 horsepower. The revolutionary Written-Pole technology, developed by EPRI and Precise Power Corporation, has also been incorporated in a motor-generator set that can operate as an uninterruptible power source for sensitive loads.



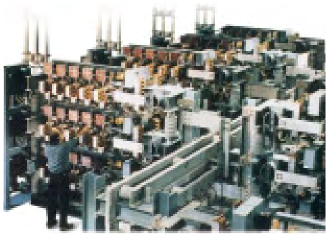
COURTESY PRECISE POWER CORP.

Written-Pole motor-generator

1996

• Incorporating key input from EPRI research, a three-year study of magnetic fields by the National Academy of Sciences concludes that available evidence "does not show that exposure to these fields presents a human-health hazard."

• The first commercial prototype of the Static Synchronous Compensator, or STATCOM, begins operation at the Tennessee Valley Authority's Sullivan substation. Developed by EPRI and Westinghouse as part of EPRI's Flexible AC Transmission System (FACTS) program, STATCOM is a solid-state controller that provides voltage support for transmission systems.



STATCOM

• The Horizon advanced lead-acid battery, developed by Electrosource with support from EPRI, ESEERCO, and five utilities, enters the commercial market. In electric vehicle applications, the maintenance-free Horizon offers a range of 100 miles between charges and greater acceleration per unit of weight than any other available battery.

DON ROPER

Energy Network Computer

• EPRI and Oracle Corporation establish a business agreement to jointly develop new information technology products for the electric power industry. The alliance is expected to lead to the development of advanced software for linking utilities with their customers and for providing customized, highly sophisticated new services.

• The first Dynamic Voltage Restorer is installed on Duke Power's system to ensure power quality for a local manufacturing plant. Developed by Westinghouse with funding from Duke and EPRI, the DVR is the most advanced of several electronic power controllers EPRI has pioneered for serving commercial and industrial utility customers.

• Two EPRI projects to advance solid oxide fuel cell technologies set new records for power density. Cells at Lawrence Berkeley National Laboratory and the University of Utah are both operated at 1.8 W/cm^2—a power density five times higher than that of conventional configurations.

• EPRI's Non-Intrusive Appliance Load-Monitoring System, a small electronic energy-use recorder that fits on a customer's meter, is released commercially by Enetics under the product name SPEED. The device can identify and transmit to a utility the power consumption patterns for an entire house or for individual appliances. Sponsors of the device's development include Consolidated Edison Company of New York, Rochester Gas and Electric, ESEERCO, and NYSERDA.

Nonintrusive load monitor

1997

• Large-scale battery energy storage takes a leap forward with the first commercial installation of the PQ2000 power quality system at a lithography plant in Georgia. Developed by EPRI and AC Battery Corporation in conjunction with General Motors' Delphi division, PQ2000 can deliver up to 2 MW of energy in about 1/240 of a second, ideal for providing ride-through power at hospitals, automated manufacturing plants, and other large facilities.

Neptune washer

• Maytag's Neptune horizontal-axis clothes washer, developed in partnership with EPRI, is commercially introduced and achieves strong sales in its first year. Thanks to its innovative design, the Neptune outcleans conventional washers, is gentler on clothes, and offers energy savings of over 60% and water savings of nearly 40%.

The Open Access Same-Time Information System, or OASIS—developed at FERC request by EPRI- and NERC-led working groups—begins operation on January 3, enabling the Internet-based sale of wholesale transmission services on the U.S. electric power grid.

• EPRI joins with SEMATECH—a consortium of major U.S. semiconductor manufacturers—to form the EPRI Center for Electronics Manufacturing. The center will address productivity, environmental, and energy issues in the electronics industry and promote collaboration between the electricity and semiconductor industries on mutually beneficial technical initiatives.

• EPRI assembles an independent expert panel to review the health aspects of using ozone as a disinfectant and sanitizer in food processing applications. The panel's affirmation of GRAS (generally recognized as safe) status for such applications—delivered with documentation to the Food and Drug Administration—clears the way for ozone's use in the $430 billion food processing industry.

COURTESY OSMONICS

Ozone generator

• The Low-Dross Aluminum Melter, developed by EPRI, the EPRI Center for Materials Production, and Process Engineering Dynamics, demonstrates 99% recovery of the aluminum contained in scrap metal. Based on a 500-kW direct-current plasma arc furnace, the melter has a thermal efficiency over three times that of gas-fired furnaces and produces only 10% of the on-site emissions.

COURTESY PROCESS ENGINEERING DYNAMICS

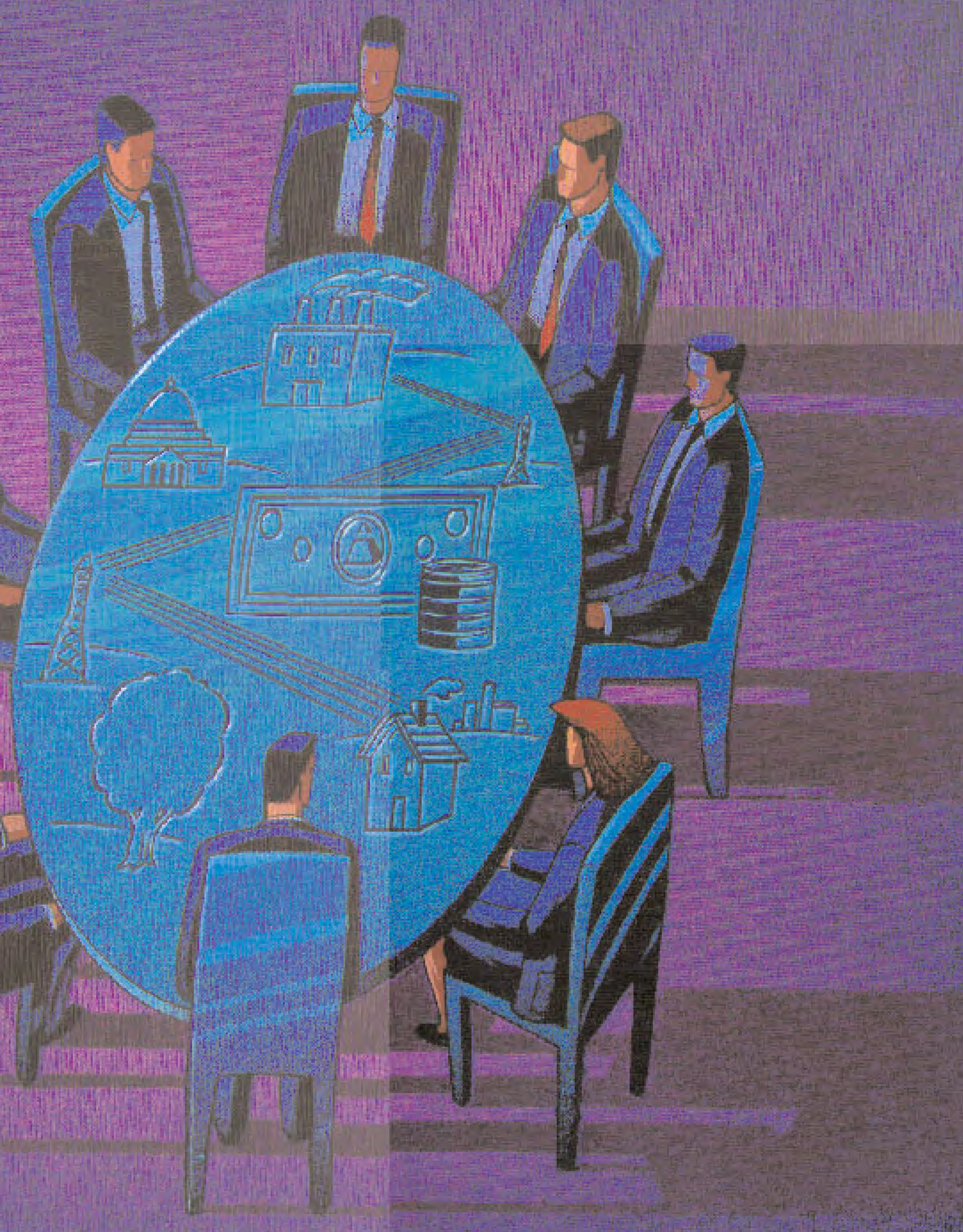
Low-Dross Aluminum Melter

Power *and the* Future

THE ELECTRIC POWER INDUSTRY is undergoing the largest restructuring in its history, with fundamental changes showing up in virtually all aspects of the business. Eight leaders and experts from inside and outside the industry provide perspective on the emerging issues and tell what they think the changes will mean for utilities and the public.

The participants are Susan F. Clark, Florida Public Service Commissioner and Chair of the NARUC Committee on Electricity; Erroll B. Davis, Jr., President and CEO of Wisconsin Power and Light Company and current Chairman of the EPRI Board; Leonard S. Hyman, Senior Industry Advisor at Smith Barney Inc.; Elizabeth Moler, Deputy Secretary of the U.S. Department of Energy; Roy Palk, President and CEO of East Kentucky Power Cooperative, Inc.; Richard H. Silverman, General Manager of Salt River Project; Robert M. White, President Emeritus of the National Academy of Engineering; and Kurt E. Yeager, President and CEO of EPRI.

DAVID TILLINGHAST



EPRI Journal: Industry restructuring has already spurred heavy merger activity, service specialization, and the entry of new players into the power business. What will the U.S. power industry look like in 10 years?

Roy Palk: I think there probably will be fewer utilities. I think there will be larger utilities. And I think there will be services that utilities normally provide now that may not be a part of their operations by that time. You'll see a lot of the consumer services spun off and put into a service company—an unregulated service company that competes on the retail side with other service companies.

Susan Clark: I do think that there will be more merger activity. And what we're likely to see is the formation of energy-related companies, not companies that deal just with electricity. One example comes to mind, certainly—the merger of Duke Power and PanEnergy. Broadening the perspective from just electricity or just gas to providing diversified energy services can give a company a real advantage in the context of customer choice. Look at what Enron is doing.

Erroll Davis: I don't know whether the industry will be bundled or unbundled, specialized or diversified 10 years from now. But it is going to be different, that's for sure. It will be whatever the market wants it to be—any changes in market structure are going to be driven by market demand. It's possible that there might be a dozen or so large generation companies, a handful of major transmission companies, and continuing mergers and acquisitions involving distribution companies.

Richard Silverman: I'm not so sure that there will be just a small number of megacompanies. We appeared to be headed that way a year or so ago, but I don't believe the merger mania that we have seen will continue. In fact, it already appears to have slowed down. I've heard some CEOs who have been involved in mergers say that they're not going to pursue more—it is so time-consuming and the approval process so drawn out, and they can't afford to wait. Therefore, they are examining, as an alternative, affiliations that can accomplish the same goal without requiring 11 approvals in three different states and time frames of two and a half years or more.

Davis: Where you'll really see a lot of new players is at the merchant level and the marketer level, marketing energy and value-added products and services. I think there you're going to see many more participants than you have today.

Elizabeth Moler: Yes, the multiplicity of players will certainly be more dramatic on the service side, but you're also seeing independent generators and merchant power plants. That was unheard of two years ago.

Leonard Hyman: I think the only thing we can be certain about is that a lot of the people who'll be around 10 years from now, or 20 years from now, are not going to be the same people who are around now.

Silverman: It's starting already. Right now you can get on the Internet and look at the 200-plus companies that are registered in California as power marketers. You will find any number of new players—from mom-and-pop operations to real estate companies, just name it. I think that large retailers—I mean people who are in the retail business generally, not just the retail power business—are going to be very active.

Right now you can get on the Internet and look at the 200-plus companies that are registered in California as power marketers. You will find any number of new players—from mom-and-pop operations to real estate companies, just name it. *—Richard Silverman*

Kurt Yeager: Basically, anyone who has a robust portal with the customer is going to be able to broker these services, so the combination of access to the markets, real-time communications with the customer, and the ability to provide that array of services will dictate the high ground. It's going to attract everybody from Sears and Microsoft to cable companies, telecommunications companies, electric utility companies, and natural gas companies. All of them have opportunities to do well in that business. The concept of the virtual utility—made up of many interactive and interdependent entities—is emerging as a very viable model for the industry.

Moler: I think that one of the exciting things about the industry—and this is based on some experience I've had in the gas industry—is that there have been dramatic changes in the players on the scene. And there are services being invented that nobody ever thought of before—utility management kinds of services, energy service companies, and combinations of portfolio management, investments, and technology to run your business in a more energy-efficient way. All of that kind of stuff is really beginning to happen.

Silverman: Credit card companies may play a big role. It makes sense for that type of large retailer to get into the business; they have the infrastructure already in place, and it's just another product.

Palk: Yes, it's very likely you could see a credit card company offering an energy incentive to use their card. And they're simply marketing—that's all they're doing. They're using a commodity as an enticement for the use of their credit card.

Davis: I think you'll see the telecommunications lines playing a bigger role, and in a similar way: you know, buy the pay-for-view movies, and we'll throw in the electricity free. So you may see some convergence of energy, telecommunications, and entertainment.

Moler: And one company doesn't have to provide all aspects of your service. Visa could handle billing. But a computer or software company would probably better handle and apply chip technology for energy management services. I want a better way to manage the thermostat in my house than anybody has ever offered me, and somebody will probably be serving that need very soon. With a number of companies and specialties involved, you can create a really incredible array of services.

Davis: That's the real payoff for having a lot of players. There are going to be marketers around who are going to customize, personalize, value-add to everybody's heart's content in those marketplaces. So you know, 10 years from now you'll get what you want when you want it. There are going to be a lot more things to choose from and a lot more people offering them.

Moler: I think that's very healthy. It will eventually be terrific for our economy and great for consumers.

Silverman: Tremendous growth in new players is not going to last forever. If you look at the experience of other deregulated industries, when the transition period is over and it all shakes out, many of these new entrants will have gone in other directions or to other businesses or will have gone belly-up. And I think you will continue to see a number of the same traditional entities that have been in the business adapt successfully: the good ones will survive; the bad ones won't. They may operate through a different corporate structure or through a subsidiary with a different name, but I think there will be a number of the same players. One of the things we learned in the eighties was to stick to our core businesses.

If federal legislation is worthwhile, we should have a federal date-certain, requiring customer choice in all states. I think there needs to be some flexibility on how competition is carried out in the states, but I don't think there should be flexibility on whether it's going to happen. *—Erroll Davis*

Journal: The rules for restructuring and retail competition are currently being drawn up on a state-by-state basis. Do you expect federal legislation on this as well?

Palk: I think if there's a role for federal legislation, it's to create an overlay so that each state has an equal starting point. I don't think it's appropriate for federal legislation to tell states how to run their own utilities. It should set goals, frame some of the problems, and point to where things should end up, but leave the details to the states. We have a federal-state partnership model that we could follow now—the interstate highway system. That system is a federal system whose operation is basically delegated to the states.

Davis: It's a good model. What if we had left the highway system up to every state? Would the highways match up at the state lines? Would the safety markings in one state be the same as those in the next? Would access controls in one state be different? There are some state differences on interstates—some are tollways, and some are not. But they all link up; they all meet certain minimum standards.

Yeager: Clearly there are certain issues that can be resolved only at the federal level. Constraints to competition have to be removed at that level. Should control extend beyond that in terms of rules for local competition? Local conditions vary a good deal, and to establish some federal mandate on what retail competition should look like would not seem appropriate. Those questions can best be resolved by the local jurisdictions on the basis of their circumstances.

Hyman: Selling electricity clearly is an interstate business, so you can't really compartmentalize it into 51 little boxes. However, the states are acting right now, moving quite fast, and I suspect that any federal legislation would end up grandfathering what the states do anyway.

Silverman: Right. The genie is out of the bottle. I believe Congress is left with a cleanup role.

Hyman: I'd like to see the legislation concentrate on those issues that really are interstate in nature—in other words, issues involving transmission and overall reliability, as opposed to worrying about how quickly you're going to get retail wheeling in Montana.

Moler: We shouldn't underestimate the importance of issues that can be addressed only at the federal level. There's a lot going on at the state level, but it *is* a business that affects interstate commerce. And there are lots of aspects of this industry—PURPA, PUHCA, reliability, transmission, international issues, reciprocity issues—that can be addressed only by federal legislation. I believe there needs to be adequate authority in the federal government to ensure that electricity supplies continue to be reliable. And you have to make sure that the industry behaves in nondiscriminatory ways, that there are lots and lots of competitors in this industry, and that the competition is fair.

Clark: In terms of legislation per se, I certainly don't think that Congressmen Schaefer and Bliley are going to back off on their project of having some sort of federal legislation that deals with bringing competition to the electric power industry. And in fact, I think states would probably support federal legislation that clarifies the jurisdiction between FERC and the states and makes it clearer that states have primary jurisdiction over retail rate matters.

Davis: To my mind, the most important national energy policy decision is whether or not we as a nation will move to put choice in the energy marketplace. If federal legislation is worthwhile, we should have a federal date-certain, requiring customer choice in all states. It would give states a clear, workable timetable for reaching the goal of retail choice. If we do not have a date-certain, I believe the federal government will have ducked its responsibilities for ordering and making rational the national energy marketplace. I think there needs to be some flexibility on how competition is carried out in the states, but I don't think there should be flexibility on whether it's going to happen.

Journal: Some experts have estimated that, when fully implemented, competition will reduce overall electricity prices by 25%. What do you think of this estimate?

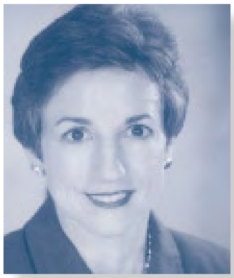
Moler: I don't have a favorite number. But I think it's clear prices will go down. We can already quantify that prices have gone down with the advent of wholesale competition and that this country is saving literally billions of dollars. I think retail competition will also spur savings, particularly once we get past the transition period.

Davis: I think that what most people don't understand is that if they look in their own state, they're liable to see 10–15% differences in electricity prices existing today. In my state of Wisconsin, if you look at residential rates, you will find that there's an 11% spread between the highest and the lowest, and that's without competition. So to me, 25% is certainly not unreasonable.

Palk: Well, I think 25% is arbitrary. And it doesn't really say anything about what you're going to experience in any particular situation. In some cases, prices may go *up* that much. If you look at the two coasts, you have power costs that are probably double those in the Midwest or the upper South or the Southeast. It depends on which end of the cost spectrum you're coming from.

Davis: Good point. Consider a jurisdiction where the rates bear no resemblance to cost of service, for example—where the rates for years and years have been instruments of social policy and where we have socked industrials to keep residential rates low. You may in fact see rates go up in some environments like that. But that's appropriate, that you pay for the value of a service.

Silverman: Well, I think 25% is high. For one thing, they're really talking about the energy component, not the entire price. So I think they perhaps misunderstand what's really going to happen. Will the energy portion of the price go down 25%? I think it's possible. I think it will be different in different parts of the country, depending on the excess capacity situation and how the market gets set up. But the energy portion of the price is just part of the equation.



I certainly think competition can bring costs down. We just have to make sure that the benefits are shared by all, that it isn't just the large users or industrial customers taking service at the transmission level that are benefiting. *—Susan Clark*

Clark: Yes, there are a lot of costs involved in distribution and transmission, costs that we're not sure will change. But I certainly think competition can bring costs down. We just have to make sure that the benefits are shared by all, that it isn't just the large users or industrial customers taking service at the transmission level that are benefiting.

Hyman: I've seen some very good estimates that would indicate you'll get at least 10%. I think some of the numbers that have been floating around are very difficult to justify as anything other than fluff concocted to make some legislation look good. I mean I've seen numbers that are absolutely mind-boggling. But I think that we're talking about the ability to get some significant savings, and I certainly think 10% or 15% represents significant savings. We're talking about $20 billion to $30 billion right there.

Yeager: Averaged overall, I would agree that 25% seems high. The Energy Information Agency recently came out with numbers that suggest the price could come down from 7¢ to about 5.5¢ a kilowatthour between now and 2020—on the order of 20% or so. Ultimately, savings to the public depend not just on competition but also on reinvestment of part of those savings. You have to remember that price is not the only issue in the new competitive sphere. There will also be a tremendous range of new services provided—value-added services. Much of the business in the future will not be a matter of selling low-cost commodity electricity at slim profit margins as much as it will be getting into higher-value, higher-margin services. I think one also has to be careful that price savings do not appear at the expense of reliability or, increasingly, power quality. We have to make the investments in infrastructure that will support reliability and the power quality demands of a digital economy.

Palk: That's correct. It doesn't matter what the price of electricity is if the system isn't reliable. You've got to think beyond the commodity portion of the service. If utilities are browbeaten simply by price and they have to forfeit necessary system maintenance in order to compete, reliability's going to suffer. It doesn't matter what the price of a commodity inside the truck is—if the truck breaks down and the product's not delivered, the consumer's not well served.

Journal: Will the United States be able to sustain the current high levels of service reliability in an increasingly dynamic, disaggregated operating environment?

Davis: My sense is that the reliability issue is largely a smoke screen thrown up by those who want to retard choice. First, most of the reliability is at the distribution-system level—the poles and wires—and that's going to remain regulated. And supply reliability will be enhanced by an open marketplace. If reliability is in fact important, it will be a basis of competition, and you will be able to select a company whose strength is reliability—a decision you cannot make today.

Yeager: Well, customer choice will certainly be a powerful element, but it seems to me the issue here is not just the differences in capability between servers but also the capability of the common carrier delivery system. To extend the truck analogy, you can switch from one trucking line to another, but if the road out there is full of potholes and it's got landslides across it, it isn't going to matter which company you deal with, the truck can't get through. If you don't invest in the technology that will keep that highway operating to increasingly higher tolerances in terms of power quality and in terms of managing the transactions that are going to be growing on that system, then reliability will be a problem for everybody.

Palk: And this isn't a hypothetical concern. We've already had a wake-up call with the recent West Coast blackout. We shouldn't have to have another train wreck to get this on the agenda. You can't just wish reliability and it happens. You have to plan for it, and you have to pay for it. If you're going to have long-distance transmission of power—especially the kind you're going to get with open access—transmission grids are going to have to be upgraded, interfaces are going to have to be upgraded. That takes capital. That takes long-term planning.

Yeager: Yes, it does. We're not going to have a lot of new delivery capacity in the foreseeable future, and yet the number of transactions has gone up dramatically in the last few years and is going to continue to go up. So managing those transactions in a relatively fixed-capacity system is going to have to be dealt with by putting in far more efficient management and switching technology. It isn't clear today who's going to be responsible for paying for these improvements, since the future ownership of the lines is unclear in many jurisdictions. Is it going to be the companies who own them now? Is it going to be the independent system operator? Right now we're in an interregnum period, with everybody saying, "Yeah, we've got to do it, but I can't justify doing it myself; somebody else is going to have to do that." Active leadership that recognizes this reality is needed.

Silverman: While the transition may be traumatic, I believe that when it all shakes out, there will be a baseline level of reliability, and customers with special needs will pay a premium for higher reliability.

Clark: We certainly need to deal with these issues of operating reliability—making sure the system continues to work on the current basis. But we're also going to need long-term reliability, and that's going to mean new generation. In Florida, the 10-year site plan we require the utilities to file with us shows that the planned reserve margin will soon fall below the level of 15%, which we have generally accepted as being appropriate. It falls below that level in the 2000–2001 time frame and declines even further, to 8%, by 2006–2007. Is somebody going to build the new power? And will they commit to anything other than a combined-cycle, natural-gas-fired facility, which they tell us they can site and build within two years? Does that mean then that no other type is going to be built, and what does that do to your fuel diversity? What if natural gas prices go way up?

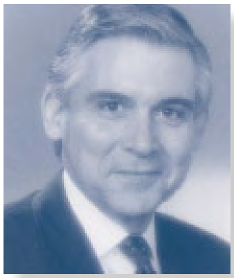
Yeager: I think that over the next 10 years, any generation shortfall *will* be made up primarily by combustion turbines and other plants that can be built quite quickly and can operate at low cost using natural gas. And I also think that as we develop a more electronically managed power grid, moving electrons around a lot more freely, we will become more comfortable operating with narrower reserve margins. But you're quite right. We will eventually need substantial new generation as we use up what we have from pockets of excess capacity, because electricity will continue to be a growth business. It's quite remarkable: since 1960, we've added between 700 and 800 billion kilowatthours in the marketplace every decade. I think you will see electricity continuing to grow steadily as a fraction of total energy used in the economy, because of its efficiency and precision advantages amplified through technology.

Journal: How important is technology for the future of the power industry, and where will new technology make the biggest difference?

Robert White: How important? It's the ball game. It's the future of the industry. Technology of all kinds is moving ahead so rapidly that it presents a wide range of opportunities, not only in the generation but in the distribution, and eventually the end uses, of electricity.

Hyman: Yes, the opportunities are tremendous. The question is, will the industry invest in them? I think one of the problems with the electricity industry is not so much that it's a low-tech industry as that many of the people in it seem to have a low-tech mind-set. Take power electronics technology, which EPRI pioneered for FACTS—the Flexible AC Transmission System. That technology could actually open up the transmission system, take care of many of our reliability concerns, and solve all kinds of other problems. You want to encourage people to put that kind of equipment in, and they're just not doing it.

Davis: That's right. You are seeing tremendous growth in electrotechnologies in areas where the market is fostering technological improvements. And where you don't see that is in the electricity industry itself, where our technology has been fundamentally unchanged for decades. I think that's due to the static constraints imposed upon us by the regulatory process. But this will change, at least in the deregulated side of the industry; it will change because the market will demand that it change. If my competitors start offering more technologically advanced solutions, I'll have to develop these capabilities too if I'm going to retain my market share.



If utilities are browbeaten simply by price and they have to forfeit necessary system maintenance in order to compete, reliability's going to suffer. It doesn't matter what the price of a commodity inside the truck is—if the truck breaks down and the product's not delivered, the consumer's not well served. *—Roy Palk*

White: This is why power companies are going to continue to make investments in programs like EPRI's. It's in their own interest. They know that new technology can increase efficiency, reduce their costs, and open up new business opportunities. It can make them more competitive.

Palk: And the value's not just in the groundbreaking, next-generation stuff either. We've used technology—I'm sure we all have—in upgrading our current system, in adding new capacity, and we haven't poured the first yard of concrete. It's simply been upgrading the plants that we have with better technology. And we've done it much, much less expensively per kilowatt than a new plant would cost.

Hyman: Yes, companies invest in R&D because they are getting their money's worth. I don't think that kind of investment is going to disappear, because, number one, it's worthwhile, and, number two, the investment is so damned small. I mean, at the moment, this industry spends only a quarter of 1% of revenues on R&D. I'd be sort of leery about investing in a company that spends less than that. They're not looking out for their future.

Moler: It's true. This country is particularly poor at doing research in regulated industries. Of course, you've got the Gas Research Institute and EPRI, and we've had the federal support of major R&D programs at DOE. They've all done excellent work. But one of the things that will happen as you get more players, I think, is that they will see an investment opportunity and a money-making opportunity and will invest much more strongly in the research needed to create new products and services.

Davis: If you look at metering, this is a good example of how the needs of the market are pushing technology to adapt and improve. We're getting better meters; we're getting more-intelligent meters that can provide both the customer and the power provider with valuable information. We'll have more miniaturization of components; we'll have more distributed generation through advanced technology development.

Yeager: This new wave of microelectronic control applications will definitely magnify the efficiency and precision advantages of electricity. That's going to lead to a lot of new markets for electricity. But I think we should be careful not to assume too much about the power of the marketplace. There's a danger in assuming that competition will automatically solve all our problems. People say electricity is going to be cheap and it's likely to get cheaper because of restructuring of the industry and so forth. If we take energy and technology for granted rather than investing in the future, we may be in for a rude awakening in a decade. After all, open markets cut both ways. As noted, natural gas, which we will be relying on heavily for the foreseeable future, may not remain as cheap as it's been if everybody wants it. It would be a tremendous mistake to let other options, including nuclear power, evolve out of the picture because we think we can instantaneously recall them. Those options aren't just going to reappear magically on the scene, particularly with the environmental and health considerations that society expects. We need to sustain a robust portfolio of energy options, as underscored by the recent PCAST [President's Committee of Advisors on Science and Technology] report.

White: The market is particularly ineffective in encouraging investments in a variety of ancillary problems, such as the environmental consequences of the production and distribution of energy. EPRI, I have to tell you, has done first-class work on what a number of us have called public-good research—that is, research in such areas as environmental and health problems that benefits and protects society in general. It's not yet clear who will be responsible for that kind of work in a restructured industry. Of course, there are incentives the federal government can use—and has used in the past—in terms of tax incentives for investments in research. It makes good sense for investments in research by private companies to get a tax break.

Yeager: Definitely—particularly at a time when many companies are so preoccupied with short-term survival that they knowingly sacrifice longer-term benefits. I think it is important that we have incentives that will encourage companies to commit themselves to research that will build the future. The winners in a business will always invest in innovation. The problem is that during the period when the winners are not yet clear—in the shakeout process—you have an interval of decline in terms of investment, as the rules and incentives change and immediate cost pressures dominate.

Journal: Do you think distributed generation will play a large role in the twenty-first century power infrastructure?

Clark: Whether or not we are going to develop into a more-distributed system, I think, will again depend on technology development—things like fuel cells and photovoltaics. If they can be implemented at a competitive price, we will see more reliance on distributed generation. If the economics are good enough, it's even possible that the grid would eventually become only a backup.

There's a danger in assuming that competition will automatically solve all our problems. If we take energy and technology for granted rather than investing in the future, we may be in for a rude awakening in a decade. *—Kurt Yeager*

Davis: It's hard to say how distributed generation technologies will function in a future system—whether they're going to be used just as peakers or backup or whether they're going to be used as the main source. The market will sort that out.

Yeager: You could almost see the coming decades as a series of competitive experiments to figure out what structure can best assimilate new technology and do so most rapidly. The distributed power generation capabilities that are coming along now—smaller combustion turbines, fuel cells, and so forth—will definitely put power generation closer and closer to the customer and provide options that give customers more control over their energy situation.

Silverman: And distributed generation will clearly offer the customer new capability. It will particularly play into the reliability area. For example, you'll see groups of businesses—perhaps a strip shopping center—investing in these miniturbines.

Palk: Right, and the smart utility will get a piece of that action—work it right into the marketing plan. You know, if you have an industrial consumer that's concerned about power quality, why not think about a distributed generator as a way of retaining that customer? Offer it as part of your service package, retaining control and ownership of the facility. Sell it as another product—high-quality power and reliability for that local load.

Yeager: In fact, why think just about big loads? The scale of these technologies is potentially small enough that distributed generation won't be restricted to just large corporations or industrial complexes; small businesses and even homes could have options other than the wires. It is strategic folly to think that the wires cannot be bypassed. Technology abhors such situations and moves rapidly to provide options.

Hyman: This brings up a very interesting point. We've talked about two key advanced technologies that are on the same developmental time track—distributed generation and FACTS. The distributed generation technologies can take people off the grid entirely and may actually create a stranded transmission and distribution investment. FACTS and other power electronics technologies, on the other hand, will make the power delivery system much more flexible and efficient. So you may actually see an enormous amount of competition between FACTS and distributed generation. I think most people see the grid remaining the backbone of the power system, overlaid with pockets of distributed generation. Well, that's probably what will happen. But you can almost see part of the grid decaying if it's priced in such a manner that people don't want to use it. Again, it's a question of economics.

I think most people see the grid remaining the backbone of the power system, overlaid with pockets of distributed generation. Well, that's probably what will happen. But you can almost see part of the grid decaying if it's priced in such a manner that people don't want to use it. *—Leonard Hyman*

White: And the economics change radically with location and situation. In the United States and other highly developed countries with central generation systems and grids, the existing system will probably remain cheapest overall. So in this country, distributed power will move into areas where it's economical to do so, where you need more flexibility or special off-grid power capabilities. But in those parts of the world where you do not have a grid and a central generation system, I think the potential for distributed generation is very, very good. The cost of putting in an entire infrastructure is so huge that distributed generation options will often win economically, even at what we'd call a pretty high cost of power.

Journal: Do you think that U.S. utilities will become a major force in international power projects?

Clark: I hope they do, for the reason that I would like to see our technology exported. I think there's a real danger if developing countries rely on technology that is more damaging to the environment. We could play a leadership role in bringing in advanced technology that will help them provide the energy they need in a way that will use the earth's resources appropriately. That kind of diversification—international investment—is also good for a company's financial position and may help its domestic capabilities as far as financing and things like that go. This should, in turn, be of benefit to customers of those utilities.

Yeager: The U.S. power industry has a great deal of strength in areas that are going to be needed as developing countries seek to increase electrification. We are particularly strong in the experience of building and operating large systems—power plants and power grids. And the reliability record of U.S. utilities is unmatched in the world, so there's a great deal of credibility about our capabilities in that area. We certainly won't be the only players in the international marketplace, but I think we are among the most formidable.

Moler: Internationally, our companies are absolutely aggressive, viable competitors. After all, we invented the IPP [independent power producer] industry and we invented project finance in this country, and that is making a difference around the world. You go to China, and they are talking project finance. That was invented here as a result of PURPA. American companies are also particularly competitive with nuclear options.

Palk: Yes. The China delegation has just been here. You know, they're looking at ordering perhaps 50 nuclear reactors. I see major utility opportunities in this area. In fact, I think the United States as a matter of public policy ought to promote our nuclear capabilities, for several reasons. One is that we have a safe design. If you look at Three Mile Island, that plant didn't blow up; it shut down, just like it was supposed to. We have lead enclosures around our reactors. You didn't have that at Chernobyl. So in terms of the U.S. design, it's very safe. And we know how to build them and how to train operators. When you consider the potential global danger of a Chernobyl-type accident, it's in our national interest that the best technology and practices be used. If China's going to purchase nuclear technology, we ought to be a vendor.

Clark: I think you could make the same case for lots of technologies, especially in light of global warming issues. We should promote the best options for this country and abroad—options that generate power efficiently while minimizing environmental impacts. I think that's necessary for two reasons: to promote a competitive generation market here and to ensure that developing countries have available technology that's not damaging to the environment.

White: Yes, and with respect to the latter, this is going to mean pursuing a reduction in the carbon content of fuels worldwide. Historically, we've seen a systematic decarbonization as we've become more efficient and as we've used other fuels.

Yeager: Electrification has been the prime mover in this robust trend. I believe carbon intensity per unit of value has declined about 1.3% a year over the last century worldwide and a little more rapidly in the United States.

White: And some countries have decarbonized much faster than we have—France, for example, which has moved toward heavy dependence on nuclear power. So what are the technologies that will increase decarbonization? The obvious ones are renewables and nuclear. I think renewables will become more important in the future: they will fill niches and will be able to provide a substantial part of our energy supply, especially in distributed uses, but they will never get to the point of being able to provide for the baseloads. I personally don't see any noncarbon source for baseload power other than nuclear. So that means that decarbonization is going to be dependent on which fossil fuel type we use—that is, using natural gas rather than coal is at least a step toward decarbonization.

Yeager: The decarbonization trend has every likelihood of continuing through the coming century and could lead to a carbon-free electricity/hydrogen energy economy, if shortsighted policies don't interfere.

Davis: It's very hard to predict how widespread decarbonization is going to be, particularly globally. Nuclear power can solve the problem for you right away. Internationally, nuclear power continues to grow; it continues to be a sought-after generating source. Here in the United States, it's still a nonstarter. This issue centers on policy choices that this country continues to avoid.

Clark: Right. We espouse the notion that we need to do something about CO_2 and other greenhouse gases. But there's also pressure to shut down our nuclear plants, and if you do that, you can't—at least currently—address CO_2 emissions issues without its being extremely expensive.

Hyman: The economic issues will be, if anything, more important to developing countries than to us, because they are poorer. I certainly can understand people in the developing world looking on the smokestack as an indication that there are jobs and saying, "You've got your jobs, but now you don't want us to have our jobs. We need the energy, and you're telling us you don't like the way we burn fuel."

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Moler: Obviously, the less-developed countries and the developing countries know that the developed countries have had all the benefits of development and have been the worst polluters. They think that we should rein our emissions in and pay the piper and that they should be given a free ride for some period of time. Any equitable solution to this issue will ultimately have to treat them differently from the developed world in some fashion, but if we're to deal with the climate change issue, ultimately they will have to become a part of the solution.

Hyman: Well, I'm not sure whether the recent round of talks in Kyoto will lead to much. If change is going to happen, we really need to work on the technologies. Just making a declaration and walking away isn't going to do a damned thing. I think that as much as possible it has to be worked out on a market basis, and I agree that we will have to deal with the developing countries differently. In fact, you're probably going to have to pay them. If I'm living down in Brazil and someone tells me that the Amazon rain forest is very, very important to the world climate, my answer would be, "I have a lot of people who don't have enough food to eat. And they're going to chop down this forest because they think they're going to be able to farm there—unless you can give them some other option." So you've *got* to pay them. Those people don't want all this pollution any more than we do. But if the choice is between the pollution and starving to death, they'll go for the pollution. The question really is, is there some way of producing energy that is not going to be that polluting?

Moler: Well, there *are* ways, and there will be even more in the future. The trouble is that, at least in the present, these options are expensive. And as you say, the solution has to work on a market basis. The whole thing with joint implementation is the notion that there may be carbon-saving opportunities abroad that are an awful lot cheaper for us to capture than capturing the same amount of carbon domestically. Taking this approach will have a positive impact from a carbon sequestration point of view and will also be very efficient economically. There are active international negotiations on this issue going on even as we speak.

Hyman: It's a good approach. Not only do you solve the problem in an efficient manner, but the participating country receives valuable expertise and you're also modernizing their facilities, which certainly will be a benefit to them.

Moler: Of course, joint implementation projects are only part of the solution. DOE has for years and years supported research on climate change and clean technologies, as has EPRI. The department has had very positive response to its Climate Challenge program, under which utilities voluntarily take steps to limit carbon emissions. That's been very exciting, and we're now looking at building upon it as we move toward an international agreement on climate change. In addition, the PCAST report may serve as a real catalyst for R&D and technology development, giving more high-level visibility to these issues.

Journal: Do you think environmental issues will continue to have as large an impact on the power business as they have had over the past two decades?

Clark: I don't know that the public will be as interested in environmental issues as it has been. It depends to a large degree on whether or not people continue to have a sense of well-being about more-basic things—their economic circumstances, crime, and the like. If they feel like those needs are being met, then I think they're more inclined to think seriously about the environment and future generations' needs. I think it also depends on what happens in the next presidential election. If Al Gore runs on an environmental platform, it may continue, but I'm not sure how responsive people will be to that. Certainly if the EPA continues to have its way, it will remain an issue.

White: I don't think we're going to see any tailing off of environmental regulations. The binding agreements on greenhouse gas emissions reductions just reached in Kyoto will have enormous impact if they are ratified by the Senate and become law. Utilities have done a reasonably good job to date on SO_2 emissions and things of this nature. But I think we're going to have a whole range of new issues that the utility industry must be concerned about. Just take the EPA's new proposals on particulates, where they're proposing to set standards for very much smaller sizes of particulates. That has major implications for utilities as well as for the automotive industry, which is a major emitter of particulates.

Silverman: Yes, the new health-related ambient air quality standards could be a big problem. Of course, what we would like to avoid are command-and-control regulatory processes, which is what we have been saddled with up until now. We need to substitute incentive-based, market-oriented programs.

Davis: We've just got to get away from command-and-control and I-know-the-best technologies. Command-and-control regulation has failed, as far as I'm concerned. And even those who claim it to be successful are ignoring how much more successful we could have been *without* command and control.

Hyman: You've got to be willing to use market mechanisms if you want to achieve these goals efficiently, and I still see an enormous amount of reluctance on the part of people to do that. They still want to actually make the decisions for other people. If you give people incentives to solve the problems themselves, they will do the job more efficiently than if you dictate a course of action, telling them, "This is what you have to do no matter what it costs."

The less-developed countries and the developing countries know that the developed countries have had all the benefits of development and have been the worst polluters. Any equitable solution to this issue will ultimately have to treat them differently from the developed world in some fashion, but if we're to deal with the climate change issue, ultimately they will have to become a part of the solution. —*Elizabeth Moler*

Palk: Exactly. Right now at East Kentucky Power we aren't running the scrubbers. We're running the precipitators, but we're using coal blending to achieve the phase one Clean Air Act requirements. We've changed the way we purchase coal, actually specifying ash content, carbon, and so on. We test the coal, and we don't pay for it until the analysis meets the purchase order specs. It's the least expensive approach for us. We're doing it, and we're making it work. As far as incentives go, I think there needs to be some expansion of clean air credits for environmental investment, for environmental research, and for participation in environmentally based projects that utilities from time to time are asked to be involved in.

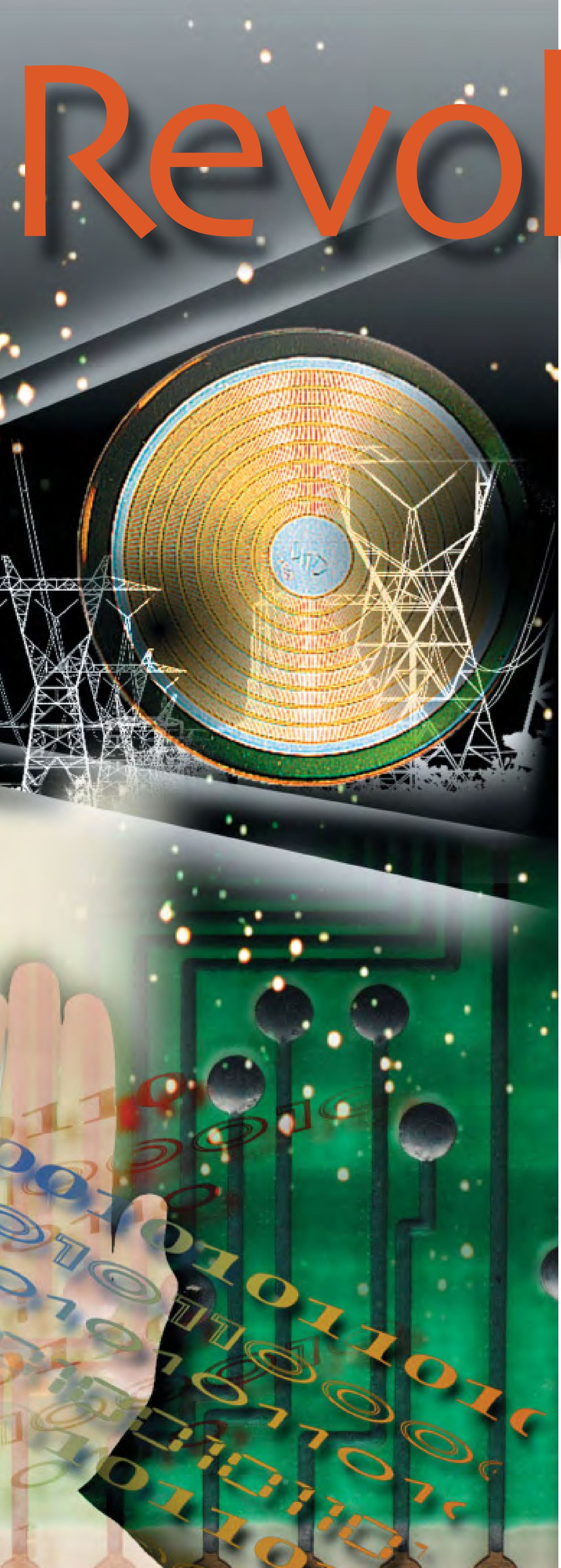
Silverman: The White House, in declaring its intentions about global warming, has mentioned the possibility of tax credits for the investor-owned utilities that participate. You know, the United States responds very strongly to economic stimuli, and so does the industry. That is not necessarily true in many parts of the rest of the world. I think tax credits are a good approach. Of course, we in the public power area of the industry need some other carrot, since we don't pay income tax. Maybe the incentive could be tied to tax-exempt financing, something of that nature.

Davis: The point is that if you really want the system to work, you've got to move from managed frameworks toward market mechanisms. You've got to provide the incentives and trust the market.

Palk: Yes, but the marketplace doesn't work in a vacuum. If competition is going to pay off substantially for customers, if we're going to see new services that really have value, and if we're going to address environmental concerns in a lasting way, innovation and advanced technology are what will make it happen. If you think the entire utility world is just going to change on its own—that there'll be no more coal burned, that prices will go down 25%, that reliability will automatically exist—it's a fairy tale. ■

The Digital

Revolution



WENDY GROSSMAN

Once the privilege of a technical elite, computers have made their way into many facets of our daily lives. Collectively, such digital technologies are transforming society and the electrical systems that power it.

We live in an age in which a hiker on a remote mountaintop can crack open a laptop computer and send an e-mail message to a friend on another continent. In the office, palm-sized computers take handwritten messages and store them as neatly typed text. We withdraw cash from automatic teller machines, shoot videos with self-focusing cameras, and drive cars with antilock brakes. At home, coffeemakers turn themselves on and off, compact disc players crank out our favorite tunes, and children amuse themselves with electronic pets.

Welcome to the digital world—a place where the 1s and 0s of basic computer code have become the common language of many electronic technologies. Twenty-five years ago, when EPRI was founded, most of us could never have imagined that any of these technologies would be a common part of our everyday lives. At that time, the microprocessor was a mere babe—only two years old—and a

by Leslie Lamarre

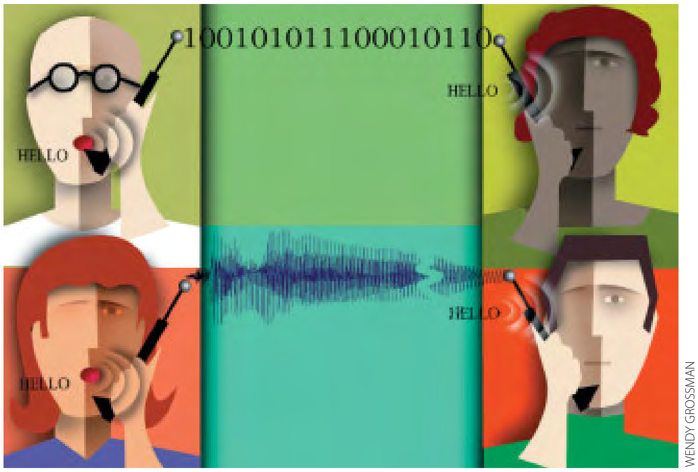
commercially successful personal computer was still four years away. Mainframe computers were the electronic brains of U.S. office environments, their centrally located power shared by multiple users.

A lot has happened in a quarter century. The personal computers on the desks of most office workers today have as much storage space as the average mainframes of 1973, which could occupy an entire room. And the processing speed of these pint-sized powerhouses is typically far greater than that of the old mainframes. Computing power continues to increase rapidly as chip developers manage to cram more and more transistors onto a wafer-thin slice of silicon. In the 40 years since its invention, the integrated circuit has gone from holding 2 transistors to holding 7.5 million.

Even more important than the exponential growth of computing power in recent years is the accessibility that has accompanied it. The ability to pack massive amounts of brainpower onto tiny chips has brought the advantages of computer technology to the general population. Indeed, the most accessible computers today are not even recognized as such. They are the microprocessors built into everything from telephones to talking dolls—and even our own bodies, as is the case with surgically implanted hearing aids. Chip makers ship some 3.5 billion of these microprocessors, or embedded computers, annually. That's almost 50 times the number of desktop computers shipped.

Some experts fully anticipate that before long microprocessors will become so cheap that they could literally be woven into fabric, making clothing capable of responding to body temperature and weather conditions to keep wearers comfortable. "After the turn of the century, everything you touch will have a chip on it," says R. Gary Daniels, former senior vice president and general manager of Motorola's Microcontroller Technologies Group. The next revolution, which is already under way, will be the incorporation of an Internet link. For instance, your car's self-diagnostic system could assess a problem and automatically relay detailed information about it to your mechanic. Similarly, a new dishwasher could e-mail its own warranty to the manufacturer as soon as you plug it in.

None of this would be feasible without digital technology—that is, electronic devices that translate audio, visual, and other types of signals into a binary language of 1s and 0s, or bits. Together the bits make up a mathematical model that is an exact duplicate of the original signal, offering the potential for perfect reception. By contrast, conventional analog technology translates signals into a continuous electrical signal, which is vulnerable to distortion during transmission. Faster transmission over greater distances and increased versatility (for example, allowing voice to become text and even to turn on a computer) are among the other advantages digital technology has over analog technology. One by one, analog consumer technologies—starting with classics like the round-faced clock and the record player—have made the move to digital format. Technologies currently in transition include cellular phones and videotapes. The first digital cellular phones hit the market in the fall of 1996, and the digital versatile disc, or DVD—a videotape replacement that looks and works like a compact disc but holds entire movies—is just now coming out.



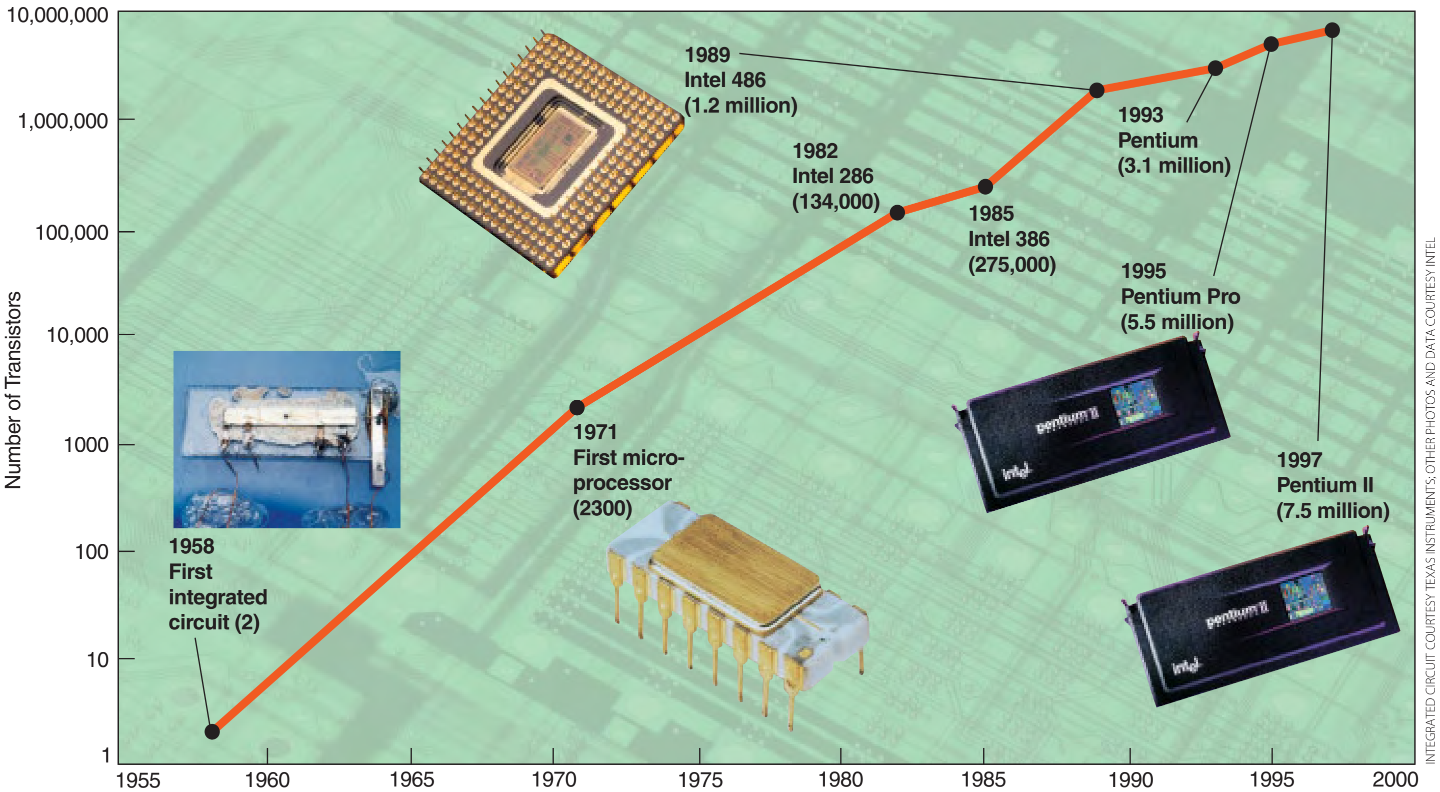
Whereas analog technologies emit a continuous electrical signal, digital technologies encode the original signal into a binary format that is virtually immune to distortion. In this example, the signal generated by a traditional cellular phone (bottom), an analog technology, picks up interference on its way to the recipient. The analog receiver converts the resulting signal—including any interference—back into a sound wave. By contrast, a digital cellular phone (top) contains a digital encoder that creates a mathematical model of the original sound wave. On the receiving end, a digital decoder recognizes and eliminates errors from the original digitized signal.

Power factor

The electric power industry is integrally involved in the digital revolution in a number of ways. At the most fundamental level, electricity is the fuel of the information age. A refinement of such earlier energy sources as steam and the gas flame, electricity and its elementary particles, electrons, offer a versatility and precision unattainable by any other energy source. Once generated, electrons instantaneously zip through transmission lines and into a multitude of sophisticated applications as diverse as word processing and laser surgery. Not only does electricity run these devices, but it also provides a vehicle for communications signals, which literally hitch a ride on electrons to arrive at their intended destination.

In powering advanced electronic devices, electricity allows us to communicate much more efficiently and accurately than ever before. In turn, electricity-run digital devices maximize the potential of this highly controllable energy form, converting electronic bits into nearly perfect sound quality, crystal-clear video images, and text that can be manipulated to a user's liking. In the words of Kurt Yeager, EPRI's president and CEO, "The microprocessor is providing a quantum leap in electricity's advantages."

The electric power industry, which has always provided a vehicle for the digital revolution, is now being directly affected by the phenomenon itself. A new generation of digital controls has begun to replace the conventional analog and pneumatic controls that have long monitored and operated power plants. Simultaneously, power companies are finding it necessary to upgrade their



Developed in 1958, 11 years after the invention of the transistor, the integrated circuit initially held only 2 transistors; today's chips hold 7.5 million.

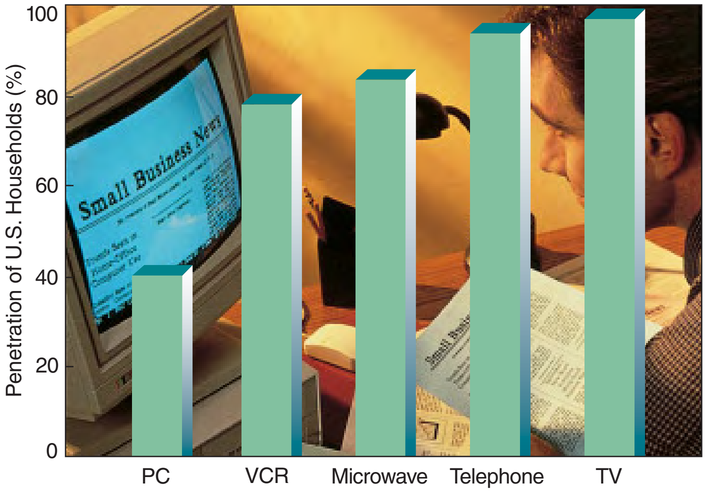
transmission and distribution networks with the same kind of advanced digital technologies that are bringing efficiency and precision to the lives of their customers. Karl Stahlkopf, EPRI's vice president for energy delivery and utilization, calls this new development the second silicon revolution. Just as the microprocessors of the first silicon revolution control the flow of information in digital technologies, the power electronic devices of the second silicon revolution (technically known as FACTS—Flexible AC Transmission System—devices and, for distribution systems, Custom Power devices) can control the flow of power, improving reliability and efficiency. The high-voltage equivalent of the transistors that compose an integrated circuit is the utility-scale thyristor, a solid-state electronic switch. Compared with integrated circuits, the thyristor-based electronic devices that control transmission systems are scaled up in power by a factor of about 500 million.

At this time, the power control devices of the second silicon revolution are expensive and not widely used in the industry. But the shift to them is expected to gain momentum rapidly for two reasons. First is the growing need to improve power quality. The digital technologies now in use in our homes, offices, and factories require high-quality power to function smoothly. Indeed, this electronic equipment is sensitive to even minor power disturbances that commonly occur on the electricity network.

EPRI's research shows that just two cycles of a 25% voltage dip or one cycle of an outage can cause unprotected integrated circuits to malfunction. Such a disturbance might result from the routine switching of capacitors on a utility system. Although this action would be virtually imperceptible to a device like an analog clock, whose second hand might simply skip a beat, it could cripple a digital clock, causing it to stop abruptly and flash on and off. The clock problem is typically more an inconvenience than anything else. But the same problem in a preprogrammed digital thermostat could mean that your heat won't come on while you're away, allowing pipes to freeze.

In the business world, the consequences are even more severe. For instance, common power disturbances can shut down factory production lines, resulting in downtime and lost products. Voltage-related power disturbances cost U.S. businesses tens of billions of dollars in lost productivity each year. And the problem is expected to become more pronounced as offices, factories, hospitals, and others deploy an increasing number of electronic technologies. Soon, power quality will become an issue that electric power companies cannot afford to ignore. Put simply, they must provide the high caliber of power required by ultrasensitive electronic equipment or risk losing customers to competitors. On the positive side, top-quality power may become a big selling point for companies that can guarantee it.

Competition itself is the second motivator for power companies to digitize their own systems. With increased competition comes a need to operate more efficiently than ever before. In a more competitive environment, consumers who face higher rates resulting from system inefficiencies can simply choose another provider. Digital technologies—from power plant controls to power electronic controllers on the grid—make possible the kind of precise and instantaneous monitoring and response that keep power generation and delivery running efficiently and reliably.



DATA DALLAS FEDERAL RESERVE BANK; PHOTO © 1998 WHITE/PACKERT/TIB

Despite the lure of the Internet and much talk about the personal computer, the majority of homes in the technology-rich United States still manage to survive without a PC.

Such precision is going to become more critical as deregulation of the industry progresses, increasing the complexity of transactions on the grid. There are already many more power transactions, and they are becoming less predictable geographically. The dramatic increase in the number of bulk power transactions on the North American power network is of concern, since the system wasn't designed to handle so many big transfers. Two blackouts in the western United States in the summer of 1996 illustrated the vulnerability of the power grid, cutting off service to millions of customers. Although bulk power transfers were not directly responsible for the outages, experts say they contribute to increasing system stress. The advanced electronic technologies power companies are beginning to deploy on their transmission systems would address this issue, since these technologies can sometimes increase individual transmission line capacity by 20–40%.

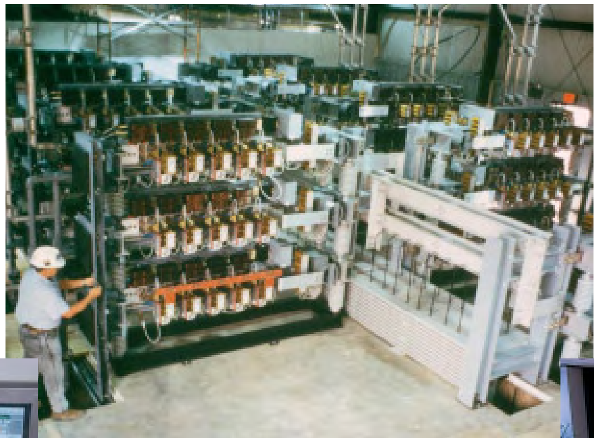
While digital control technologies are just beginning to make inroads in the industry, digital communications technologies are already playing a significant role. A year ago, the electric utility industry established an Internet-based communications system to serve as the basis for power transmission transactions in a deregulated market. Now planning is under way for a similar electronic system for the sale of bulk power itself. Although it is not yet clear whether the Internet or a private network will be the medium for these transactions, a system is expected to be in place by early 1999.

Making sense

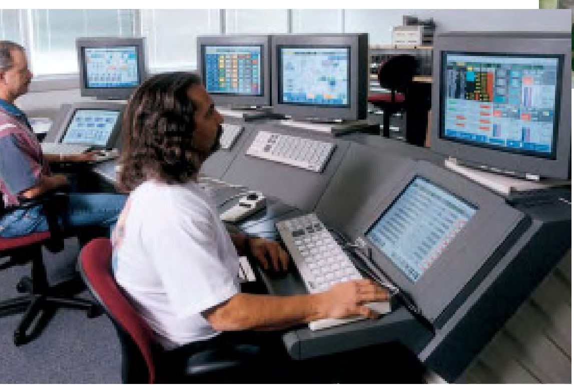
Perhaps the least recognized aspect of the digital revolution is sensor technology, so named for its capacity to mimic the human senses. Just as the human senses provide input for the brain to process, sensors feed information to microprocessors, which supply the intelligence to apply it. Already widely used in both home and office environments, sensor technologies are adding a new dimension of intelligence to digital devices. Carbon monoxide detectors sniff out a potentially lethal gas that is imperceptible to the human nose; motion sensors detect a person's presence in a room and automatically turn on lights; and clothes dryers equipped with moisture sensors shut off when garments are dry. Power companies are even using sensors to turn off noncritical, power-hungry appliances (such as water heaters) during periods of peak power use, saving customers money on their energy bills.

The capabilities of future sensor technologies are limited only by the imagination. In fact, experts predict that the coming decade will be the era of the low-cost solid-state sensor, much as the 1980s were for the microprocessor and the 1990s are for the Internet. The home of the future might have sensors that, detecting when the occupants have arisen, trigger the coffeemaker to brew and even start the shower. Sensors in high-tech running shoes could respond to an athlete's movement to optimize support. And automakers are already involved in developing sensors to improve the safety of air bags. This research was spurred by the recognition that air bags, which

COURTESY TENNESSEE VALLEY AUTHORITY



STATCOM for transmission voltage support



Digital power plant controls

Like their customers, power companies are increasingly relying on digital technologies for business advantage. In the power plant, digital control panels increase efficiency, and on the delivery grid, advanced electronic controllers like STATCOM improve reliability and power quality. Meanwhile, digital communications technologies enable industry-wide electricity trading.

CHRIS SALVO/ELECTRIC CLEARINGHOUSE

Electricity trading floor

Computer technology is embedded in a variety of everyday products, like those shown here. Today such hidden computers outnumber their desktop counterparts 50 to 1.

PHOTOS (CLOCKWISE FROM GUITAR) COURTESY TANDY; MICROSOFT CORP.; WHIRLPOOL CORP.; BLACK & DECKER; BANDI; KITCHENAID

deploy at a rate of nearly 200 miles per hour, were responsible for the death of some children and small adults. The smart air bags now under development have sensors that determine how quickly or powerfully a bag should expand, given a passenger's size and position.

Just as sensors have added a new dimension of intelligence to consumer devices, they also offer the opportunity to vastly improve the capabilities of electric power systems. In fact, advanced sensor technologies using fiber optics and magnetic resonance imaging are beginning to be deployed to improve the efficiency of the North American power network. Smart sensor technologies have obvious advantages over the conventional sensors that monitor variables like temperature, pressure, and power flow. The conventional technologies all track motion of some sort. In a strain gage, for instance, the movement of a lever arm indicates the level of strain on a given component. Such mechanical sensors must be calibrated fairly regularly to maintain accuracy—a process that is expensive and time-consuming. And even slight sensor inaccuracies can translate into significant financial losses. Extensive EPRI tests at one utility indicated that despite the company's best efforts to keep its temperature sensors calibrated, they were off by 8–10°F out of 1000°F. The resulting efficiency losses amounted to $50,000 per fossil plant annually.

Advanced sensors for application in the power industry have a more precise basis than motion. For instance, an optical strain sensor uses light wavelengths to determine the level of strain on a given power plant component. The sensor data can be used to automatically adjust the variable of concern. The process is analogous to that of a digital home thermostat, which uses sensors to detect the temperature inside a house and an actuator to turn the furnace on and off as needed.

When used with digital controls, sensors offer power companies a reliable means of operating and maintaining their systems at higher efficiency and narrower margins. In fact, EPRI's research indicates that state-of-the-art digital control systems can regulate processes with less than 0.25% uncertainty, compared with 2–3% for analog control systems. A limited number of advanced sensors have been developed for use in power plants and on transmission and distribution systems. The need for increased efficiency that will come with a more competitive business environment is expected to lead to their widespread use.

Digital democracy

All the hype about the information age might lead one to believe that most people have access to a personal computer. However, even in the United States, which gave birth to the PC, only 40% of households actually own one of these devices. And an even smaller percentage have PCs with enough power and software to take advantage of the Internet. By contrast, 98% of U.S. homes have television sets, 94% have telephones, 84% have microwave ovens, and 79% have videocassette recorders.

A combination of high cost and complexity of use has limited the PC's adoption in U.S. homes. This has led to an information society made up of a technical elite, who can access the Internet from their offices and homes, and the unconnected masses. Some groups are working to rectify this situation by making the technology available to those without it. For instance, the Clinton administration, through its educational technology initiative, is working with the telecommunications industry and others to connect every classroom and library in the country to the information superhighway by the year 2000.

Another approach to closing the information gap is to make computer technology more affordable and deliver it in a variety of user-friendly, accessible products—advances that are already under way. Technophiles go so far as to say that sophisticated, Internet-based technologies now under development hold the key to bridging the gap between the haves and the have-nots of the information age. They fully expect that just as tiny crash-proof computers (in the form of microprocessors) have made their way into everything from telephone answering machines to teddy bears, the Internet too will become embedded in commonly used devices, making it easily accessible even to users who don't know the difference between hardware and software.

One outcome of this vision that will soon hit the market is the so-called information appliance—a device that combines the power of a computer with the convenience and affordability of a household appliance. These networked devices, which are expected to cost between $5 and $350, are designed to accomplish specific tasks. For instance, an information appliance in the kitchen could provide an electronic screen and keyboard giving users instant Internet or CD-ROM access to recipes and information on ingredients. Similarly, telephones could incorporate electronic yellow pages that are automatically updated daily via the Internet, freeing users from the chore of storing and accessing cumbersome phone books.

Farzad Dibachi, president and cofounder of Diba, an information appliance software technology company acquired by Sun Microsystems last August, believes these devices will play a role similar to that of the original household appliances in the Industrial Revolution. "Home appliances helped speed the democratization of society by providing the lower and newly emerging middle classes with what had long been available only to the rich—cleanliness and leisure time," Dibachi says. "By providing simple, easy access to information in the same way that original appliances provided simple and easy automation of common household chores, the information appliance promises to democratize information access, narrowing the gap between technology's haves and have-nots."

A variation of the information appliance concept is already on the market: diskless digital devices that offer Internet access through a television set. These devices cost about the same as VCRs and simply plug into a cable outlet or a telephone line. With them, users can surf the Net from the family room sofa—calling up bank account balances and sports scores, playing interactive games, or sending e-mail messages. Because data and applications are downloaded from a network server, there is no need to install or upgrade software. In fact, the latest software applications are automatically activated as users go about their business on-line. One such Internet device, developed by Network Computer, Inc., is accessed by using a smart card containing a silicon chip that identifies the user and authorizes his or her entry to the network. Eventually, the smart card will be used to make on-line purchases. NCI's network computer was released in a TV set-top box format last fall, and other versions are under development, including a desktop model designed for the home and a telephone-based model.

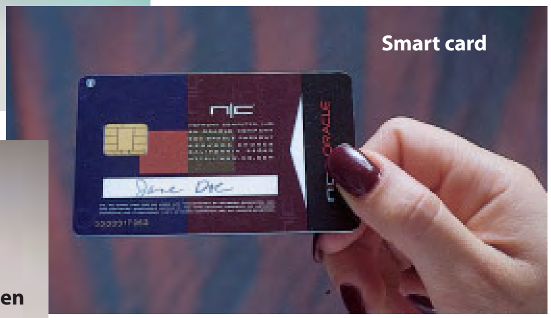
EPRI is working with Oracle Corporation and others to help power companies take full advantage of the television-based network computer as a tool for establishing company identity, improving customer

Sun Tour Director prototype

PROTOTYPES COURTESY SUN MICROSYSTEMS

Set-top network computer

COURTESY NETWORK COMPUTER, INC.



Smart card

Sun Kitchen prototype

To bring the benefits of the information age to the unwired masses, technology companies are developing devices that combine the power of a computer with the convenience and affordability of a household appliance. By accessing the Internet or CD-ROMs, each of these information appliances will perform a specific task, from fetching recipes to helping tourists navigate city streets. Already on the market are devices that provide Internet access through a television. Users of NCI's set-top network computer, for example, access the network with a smart card, which stores up to 6 kilobytes of personal information.

loyalty, and increasing revenues. One strategy is to develop community-oriented Web sites that power companies and other utilities can use as a vehicle for customer communications and services. The companies would work with local groups and merchants in their service territories to offer on-line community-related services, such as publicizing community and school events. Such a Web site, which would feature the power company or utility logo, could draw revenue from local advertisers—an essentially untapped source, since almost all of today's Internet advertising is national in scope. To encourage use of the community-oriented Web sites, the power companies could offer Internet access devices to their residential and small commercial customers for a nominal fee. The potential for what power companies could offer on these sites extends well beyond community-based services to include home security, entertainment, and energy management. Eventually, consumers could even pay their power bills on-line.

Knowledge is power—but whose?

When Francis Bacon penned the phrase "Knowledge is power" at the height of the Renaissance in 1597, he had no idea how literal this statement would become at the brink of the new millennium. Indeed, some visionaries view the microprocessor as the steam engine of the information age, leveraging the human mind much as the steam generator leveraged human muscle during the Industrial Revolution. Today, digital technologies bring the power of knowledge to a multitude of users—including new parents monitoring their baby in another room, drivers using E-Z passes to zip through toll stations, job candidates searching and applying for openings on-line, and corporations tracking consumer and competitor hits on their Web sites.

Accompanying all the advantages that these various forms of knowledge provide, however, is the concern that the knowledge—and hence the power—could fall into the wrong hands. The Internet has added a new dimension of paranoia to this concern, as was dramatized in the 1995 movie *The Net,* in which the heroine becomes a victim of identity theft in cyberspace. Most often, the consequence of easy access to personal information on the Internet is more an annoyance than a criminal assault. Typically, the data gatherers of cyberspace collect information about online consumers and sell it to marketing companies interested in targeting those consumers. The result is a pile of catalogs and other junk mail. But the potential for far more serious violations does exist.

STEVEN BOLJONIS

SAM OGDEN PHOTOGRAPHY

Leading scientists say computers of the future will be more like humans. Progress on this front is already under way. Shown here are a talking computer under development at AT&T and a device from SensAble Technologies called the Phantom, which uses force-feedback technology to enable users to feel and manipulate objects in cyberspace.

"We're in the midst of a global interconnection that is happening much faster than electrification did a century ago and is expected to have consequences at least as profound," Joshua Quittner, news director of the Pathfinder on-line information network, wrote in an article on privacy for *Time* magazine last August. Quittner described his own experience with a digital hacker who forwarded all his telephone calls to an out-of-state answering machine. "If our hacker had been truly evil and omnipotent . . . he could have sabotaged my credit rating. He could have eavesdropped on my telephone conversations or siphoned off my e-mail. He could have called in my mortgage, discontinued my health insurance, or obliterated my Social Security number." In the electric power industry, one fear is that clever hackers could potentially intervene in electricity transactions and cause spot or even widespread outages. Many experts play down this potential, citing tight security measures—such as sophisticated encryption and fire walls—that have been implemented to thwart such activity.

Still, the threat of cybercrime on both personal and business levels is very real. Some even go so far as to say that so-called information warfare will ultimately accompany physical warfare as a means of bringing an enemy to its knees. For example, given the technology and the motivation, warring countries could infiltrate each other's cyberspace and wreak havoc on government, air traffic control, and telecommunications. Rather than missiles, the weapons of choice could well be computer viruses, and the country with the more sophisticated information technology would have the upper hand. While all of this may sound like science fiction, the National Security Agency has already recruited hundreds of people to work on the issue of information warfare, according to a report in *The Economist* magazine last year. As observers stress, the digital revolution—like any new opportunity—has brought new risks. And the process of developing technical responses to these dangers is part of the revolution too.

What's next?

As the development of information technologies continues to gain momentum, we can't help but wonder what's next. Although impressive advances in computing power are a preoccupation of society right now, many of the country's leading computer scientists fully expect that digital processing power, storage space, and transmission capacity will no longer be issues in the future. Some of these scientists have turned instead to the broader challenge of how to pattern computers on living creatures—that is, how to develop computers that can extend our senses, respond to our voices, and learn from their own mistakes.

Power engineers are currently exploring the potential for such computers to optimize the efficiency and reliability of the North American power network. Martin Wildberger, who oversees related research at EPRI, envisions the dispersion of sophisticated computer technology throughout the power network—both within power plants and on transmission and distribution systems. These "independent intelligent agents" would operate locally with minimal supervisory control. Working in conjunction with advanced sensors and controllers, the agents would be able to respond instantaneously and optimally to any potential problem on the grid. For instance, a downed wire might add stress to another line—stress that pushes the line above its rated capacity. But rather than automatically cutting power flow to that line, the agent in charge might "reason" that the consequences of a little extra stress on this line for a short time are not severe enough to warrant the loss of power to millions of customers. Wildberger says that such adaptive control capability is dependent on the widespread deployment of utility-scale power electronics and is some 15–20 years away.

Advanced computer-based control technologies—combined with such other innovations as superconducting cables, advanced energy storage technologies, and small, dispersed power generation units—will help the electricity industry provide the high level of reliability that digital customers of the future will almost certainly expect. For without such reliability, how will these customers manage to function in a world where virtual reality will be integral to education and job training, where intuitive computing supplements human decision making, and where the boundaries between humans and machines are no longer very clearly defined? "It's difficult to project precisely what's going to happen 20 years down the road, given the explosive growth of information technologies and capabilities," says EPRI's Yeager. "But what we do know is that electricity is going to be the prime mover for it all." ■

PHOTOS (LEFT TO RIGHT) COURTESY APPLE COMPUTER; NATIONAL ACADEMY PRESS (www.nap.edu), REPRINTED FROM *REINVENTING SCHOOLS: THE TECHNOLOGY IS NOW*; CROCKER MIDDLE SCHOOL.

The Digital

Digital technology pervades adult lives, but

Margaret Lee designs a mean home page; Dexter Chiang helps teachers navigate the World Wide Web; Timothy Hollingsworth is in charge of a computer server shared by 450 people; and Andrew Wilson runs his own game-hacking Web site in his spare time.

These people are children—all students at Crocker Middle School in Hillsborough, California. Located on the periphery of Silicon Valley in one of the country's wealthiest school districts, Crocker admittedly is not your typical educational establishment. Still, the enthusiasm these kids express for digital technology reflects a national trend. And the implications for the future are significant.

According to a national poll conducted by *Newsweek* magazine last year, 89% of teenagers use computers at least several times a week, 61% surf the Internet, and 98% credit technology for making a positive difference in their lives. The research of other organizations supports such findings. The U.S. Census Bureau says about 60% of 3- to 17-year-olds use computers today—twice as many as in 1984. And according to the Children's Partnership of Santa Monica, California, some 10 million kids were using the Internet as of last December, a fivefold increase in just 18 months. Responding to this trend, major Internet access providers like America Online, Compuserve, and Microsoft Network are expanding their child-oriented services.

"Children take to programming like ducks to water," says Seymour Papert, the Lego Professor of Learning Research at the Massachusetts Institute of Technology's Media Laboratory, in his book *The Connected Family: Bridging the Digital Generation Gap*. Chris Fitzgerald-Walsh, a teacher and technology mentor at Crocker, concurs. "These kids were born with microchips in their mouths," he says, referring (in only a slight exaggeration of reality) to his students. "They are my first real digital generation."

Indeed, many of the kids in Fitzgerald-Walsh's class were born in 1984, the year the Macintosh arrived, ushering in an era of friendly computer technology. Unlike their parents, who grew up in a world where interactive play meant games like tag and red rover, these youngsters were raised on Nintendo and educational software programs that blur the line between play and learning. To them, digital technology has been a friend. In fact, children of the digital generation have taken so readily to computers, they often find themselves teaching their parents how to use them.

"Nobody else in my house really knows how to use the computer," shrugs 13-year-old Devin Scheifele, who is helping administer Crocker's new student network and was among a group of Fitzgerald-Walsh's students who gathered recently to talk about technology. Classmate Chris Johnson agrees, noting that

Generation

children are the ones taking it to new heights.

his parents often enlist his help. "It's like, 'How do you turn it on? How do you sign on?'" he says, rolling his eyes.

What is it about computer technology that appeals to kids? Bill Gates, founder and CEO of Microsoft, recalls being drawn in by the machine's power at the age of 13. "Here was an enormous, expensive, grown-up machine, and we, the kids, could control it. We were too young to drive or do any of the other fun-seeming adult activities, but we could give this big machine orders and it would always obey." Today's digital children get a much earlier start, many pointing and clicking well before they can read and write.

Giving children control over the technology they love is a new trend in education. At Crocker, a group of students called the Navigators are—under Fitzgerald-Walsh's direction—literally in charge of the student network. This means establishing and administering e-mail accounts and work folders for all 450 students, managing the help desk (which involves assisting students and teachers alike with all kinds of computer-related problems), and redesigning the school's Web site.

"They are doing this literally because they love to do it," says Fitzgerald-Walsh, noting that the school benefits too; rather than hiring a single, overworked adult expert to troubleshoot computer problems for the entire school, Fitzgerald-Walsh's team of 15 student experts have been trained to provide computer know-how as needed. "The kids just gain enormous confidence and skills by being the experts," says Fitzgerald-Walsh—especially when it comes to helping the adults. "They like it when they know a little more than us about something," concedes Principal Larry Raffo, who was rescued by one of Fitzgerald-Walsh's Navigators when he experienced e-mail problems last fall.

Other schools are taking different approaches to encouraging student innovation with digital technologies. In Whitehouse, Ohio, students at Anthony Wayne Junior High are diving into multimedia; in one project, they used computer programs to produce a claymation movie synchronized to the "Waltz of the Flowers" from Tchaikovsky's *Nutcracker Suite*. In Lexington, Massachusetts, fifth graders at the Maria Hastings School have applied the principles of modern genetics to breed dozens of colorful dragons on personal computers. In Maryland, students from six high schools collaborated over the Internet to identify the epicenter of a simulated earthquake. And millions of students in other U.S. school districts are participating in the Jason Project, through which they help gather data during deep-sea expeditions broadcast live, via satellite, from research sites off Bermuda and in California's Monterey Bay.

Despite such progress, experts agree that the public school system as a whole is lagging behind the rest of society in its technological evolution. And they are particularly concerned that some children might be missing out. "One of the biggest challenges is to make sure that the technological advancements—computer skills and Internet access—don't leave certain kids behind, particularly kids whose families can't afford computer and Internet access, disabled kids, kids in rural areas, and girls," says Wendy Lazarus, codirector of the Children's Partnership. "If information technologies are going to be part of kids' lives and they're going to give kids important job skills, then we've got to make sure all kids have access."

Reed Hundt, former chairman of the Federal Communications Commission, predicts that by the year 2000, 60% of new jobs will require computer and networking skills. "When all these computer-savvy kids get into the job market, it will be a far more computer-literate population. And the effect on business may be that companies gradually move to doing things differently, not just doing them faster or more efficiently," says David Elkind, professor of child study at Tufts University.

The question, however, is whether the young and technologically fearless will ultimately be sobered by the realities of adult life or whether the digital passion of their youth will follow them into the business world. Observers suggest the latter. They envision a business world dominated by leaders who approach their profession with the same gusto they showed in their first round of Nintendo. The result will be a far more dynamic business environment and one in which, needless to say, expectations for technology are quite high.

"I think in the future the Internet is going to be real-time, which means instantaneous," says Andrew Wilson. "There are going to be no delays, no lags. I think computers are going to be completely integrated into the Internet. Everything will be done through servers. You won't need hard drives much anymore." Eventually, he predicts, computers will be able to think for themselves.

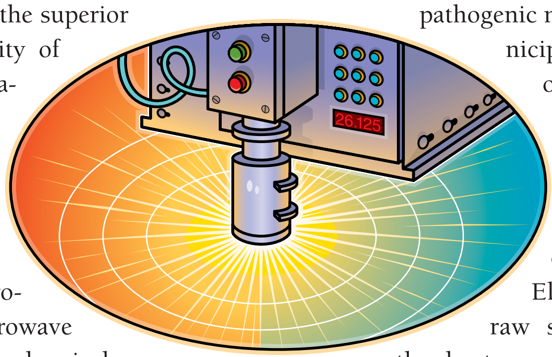
For many young digerati, technology appears to have no limits. As Chris Johnson puts it, in 20 years computers will be so easy to operate, "even your parents won't have to ask how to use them." □

Technologies *for* Tomorrow

The shape of our future will be largely determined by how we generate and apply technological innovation—the most powerful force for progress in the modern world. The 10 technologies highlighted here are poised to have a strong transformative effect on the power industry and on the whole of society in the coming decades.

Industrial Electrotechnologies

Emerging electrotechnologies for the industrial and agricultural sectors are changing the way products and goods are made. With these technologies, manufacturers and producers can cut operating costs, boost productivity, and increase profits. The new technologies take full advantage of the superior cleanliness, precision, and controllability of electricity to minimize the use of raw materials and maximize product output. In every instance, they represent a more energy-efficient approach than conventional processes and have less environmental impact.



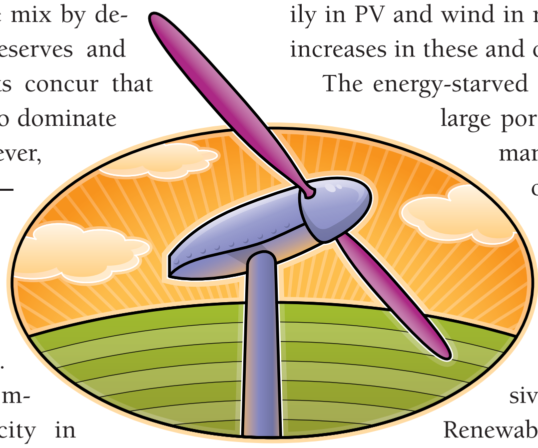
Electrotechnologies for industrial productivity span a wide range, from microwave processing, electroseparation, and electrochemical synthesis in the chemicals industry to ultrasound processing, ozone disinfection, and radio-frequency drying technologies in the textile and carpet industries. Elsewhere, pulp and paper producers are finding opportunities to reduce costs and improve environmental performance through the use of membrane separation, biofiltration, and other electrotechnologies.

Food processing facilities are increasingly turning to such technologies as ozonation and ultraviolet light for sterilization. New technologies like electron-beam processing and electronic pasteurization hold promise for eliminating health risks from pathogenic microorganisms in beef and poultry. Municipal water treatment plants, meanwhile, offer potential applications for a wide range of disinfection and desalination technologies, including ozonation and microfiltration.

In metals production, the use of electric arc furnaces continues to grow. Electric steelmaking's share of domestic raw steel production is 40% and rising, thanks to such advances as thin-slab casting, improved computer control, ladle refining, and burners that increase melt rate. Further along the value-added chain, materials fabricators are using infrared and ultraviolet curing in coating and finishing processes, electrically heated vacuum furnaces for processing specialty steels, and all-electric plastic-injection-molding machines.

Renewable Energy

By virtually all accounts, renewable energy resources will be an increasingly important part of the power generation mix over the next several decades. Not only do these technologies help reduce global carbon emissions, but they also add some much-needed flexibility to the energy resource mix by decreasing our dependence on limited reserves and overseas sources of fossil fuels. Experts concur that hydropower and biomass will continue to dominate the renewables arena for some time. However, the rising stars of the renewables world—wind power and photovoltaics (PV)—are on track to become strong players in the energy market of the next century.



Wind power is the fastest-growing electricity technology currently available. Wind-generated electricity is already competitive with fossil-fuel-based electricity in some locations, and installed wind power capacity now exceeds 7600 MW worldwide. Meanwhile, PV electricity—although currently three to four times the cost of conventional, delivered electricity—is seeing impressive growth worldwide. PV is particularly attractive for applications not served by the power grid. Advanced thin-film technology (a much less expensive option than crystalline silicon technology) is rapidly entering commercial-scale production, with 25 MW of manufacturing capacity installed in the past two years. Perhaps even more promising than the technical developments in renewables are the resounding endorsements from major energy companies like Enron, Shell, and British Petroleum, which have invested heavily in PV and wind in recent years and are planning significant increases in these and other renewables efforts.

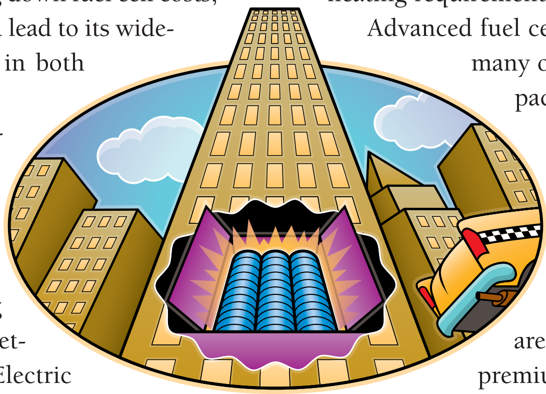
The energy-starved developing world, which accounts for a large portion of the projected new electricity demand over the next 20 years, is considered one of the biggest markets for renewables. Many of these countries are attracted to the technologies' modular nature; located close to the user, the units are far cheaper and quicker to install than central-station power plants and their extensive lengths of transmission line.

Renewables are also gaining favor in industrialized countries. In Europe, strong public support for clean energy is causing the renewables market to expand rapidly. Renewables already account for 6% of total energy there, and the Europeans have recently announced an aggressive goal to double this contribution by 2010. In the United States, national surveys show that well over half of consumers are willing to pay more for green power, and a number of power companies are now offering this option.

ILLUSTRATIONS BY JEFFREY PELO

Fuel Cells

Originally developed for onboard power in spacecraft, electrochemical fuel cell generators are entering commercial use in terrestrial applications, thanks to government subsidies. As ongoing R&D and improved design bring down fuel cell costs, the technology's many advantages should lead to its widespread deployment in the years ahead, in both grid-connected and off-grid applications.



Fuel cells offer compact, modular packaging, high efficiency, fuel and siting flexibility, and pollution-free operation. They could become widely used as distributed premium-power sources at industrial sites and in manufacturing plants, office buildings, institutional settings, and perhaps eventually homes. Electric power companies may deploy them at their own or customer sites to provide combined heat and power services. And there are efforts to develop practical vehicles with fuel cells instead of batteries for powering electric and hybrid motor drives.

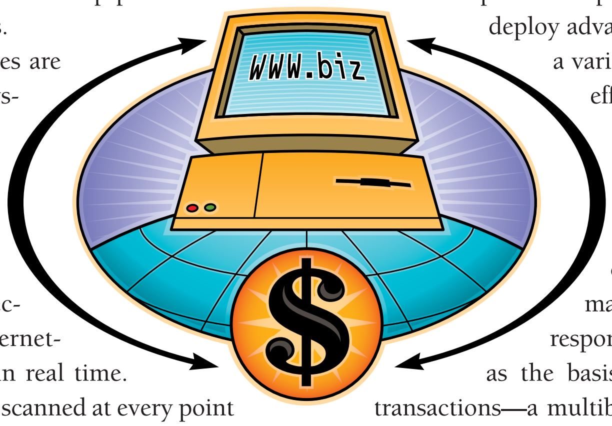
In many areas, fuel cells are expected to provide strong competition to commercial and industrial electricity rates at the point of end use. As part of an integrated ecological design, for example, a major new skyscraper under construction at Times Square in New York City will include fuel cells for powering external lighting and serving some of the building's heating requirements.

Advanced fuel cell technologies also are expected to find many off-grid applications as lightweight, compact, remote portable power generators. Several electric power companies are already positioned in joint ventures with fuel cell developers to market the systems to customers that have special power quality and reliability requirements. Other energy service providers are planning to market fuel cells as part of premium-power offerings.

Because of their high efficiency in converting natural gas, methanol, hydrogen, and even gasoline into electricity, fuel cells offer the lowest carbon dioxide emissions of any fossil power system. Moreover, the hot exhaust of solid oxide fuel cells makes them ideally suited for combination with small gas turbines in a modular power plant package that could reach efficiencies of over 70%—the highest of any thermal power cycle.

Electronic Commerce

Business use of the Internet started out as a way of gaining company visibility through "brochureware." Today, however, the focus is on the bottom line: reducing costs, improving customer service, speeding up transactions, and eliminating middlemen. Electronic commerce will soon be critical to success in the business world; companies that fail to keep pace will lose out to Internet-savvy competitors.



An increasing number of businesses are deploying advanced information systems to enhance all kinds of transactions, including those within a given company, those between a company and its suppliers, and those between a company and its customers. Federal Express, one of the pioneers of electronic commerce, established an Internet-based system for tracking packages in real time. Each package carries a bar code that is scanned at every point of transfer along its route. The scanned data flow directly onto the company's Web site, where customers can view it instantly. Not only does the system save time and frustration on the customer's part, but it saves Federal Express money.

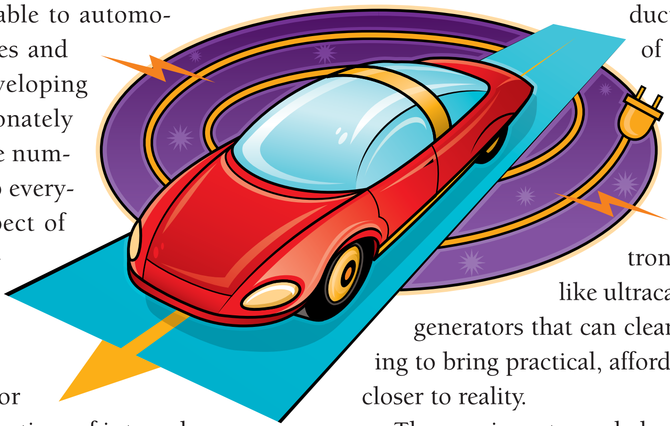
Sun Microsystems reports that 65% of its manufacturing purchase orders were filled electronically in fiscal year 1997 and that its electronic sales totaled over $1.3 billion in the United States alone. At Cisco Systems, on-line sales of networking and communications products now amount to $9 million daily. And industry analysts estimate General Electric is saving $1 billion to $3 billion in purchased materials costs by using the Internet.

Electric power companies are individually just beginning to deploy advanced information systems to perform a variety of tasks more efficiently and cost-effectively, from billing to the dispatch of emergency crews. But the industry as a whole has created one of the biggest business-to-business uses of the Internet to date with the establishment of the Open Access Same-Time Information System. Launched a year ago in response to a federal mandate, OASIS serves as the basis for U.S. bulk power transmission transactions—a multibillion dollar market. Rather than using telephones and fax machines to negotiate transmission paths and fees, buyers of transmission services now go on-line.

Although the advantages of electronic commerce are obvious, companies have barely scratched the surface of its possibilities. Some industry observers say that by the year 2000, $1 trillion in business will be conducted over the Internet.

Electric Vehicles

Electric vehicles can carry the world toward a zero-emission, decarbonized transportation future. Today in the United States, half of total oil consumption (an amount equal to oil imports), half of urban air pollution, and a quarter of greenhouse gas emissions are attributable to automobiles. In other industrial countries and in the growing cities of the developing world, cars extract a proportionately similar or even greater toll. As the number of vehicles continues to climb everywhere, the world faces the prospect of paying increasingly painful economic, health-related, and political costs for its dependence on oil-fueled transportation.



The only sustainable option for effectively addressing the twin negatives of internal combustion vehicles—air pollution and greenhouse gas emissions—is electric transportation, including passenger cars, commercial vans, buses, light-rail and subway systems, and perhaps, sometime in the next century, high-speed magnetic levitation trains. Electrically powered motorbikes and scooters could also play a critical role in sustainable mobility, particularly in Asian countries.

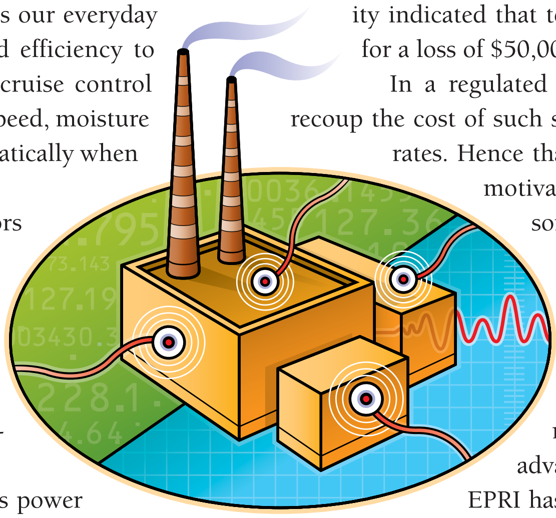
All of the world's major automobile manufacturers are developing electric or hybrid-electric vehicles for commercial introduction in the next decade. As a result of recent technological developments and collaborative R&D, these vehicles are poised to rival their gasoline-powered counterparts in performance. Emerging new technologies—advanced batteries, electronic controls, energy storage options like ultracapacitors and flywheels, and fuel cell generators that can cleanly convert various fuels—are helping to bring practical, affordable electric cars and other vehicles closer to reality.

The race is on to apply leading-edge technologies in advanced electric vehicles that consumers will find attractive in both performance and price and that will change the way we get around. The stakes are huge: technological leadership that opens the way to enormous export markets and to greener, sustainable modes of transportation.

Advanced Sensors

Experts predict that the first decade of the new millennium will be the era of the low-cost solid-state sensor. Already, advanced sensor technology pervades our everyday lives, adding comfort, convenience, and efficiency to even the most mundane tasks. Just as cruise control sensors help our cars maintain a steady speed, moisture sensors turn our clothes dryers off automatically when loads are dry.

In the electric power industry, sensors are more than a matter of convenience. In fact, given the greater efficiencies they make possible through automatic, real-time adaptation and fine-tuning of system operation, they just might become a matter of survival in a more competitive energy market.



Sensors are widely deployed in today's power plants and transmission and distribution systems to track temperature, pressure, power flow, and other variables. However, the bulk of the sensors in use are based on technology that is over 20 years old. EPRI's extensive testing of existing sensors indicates that despite the best efforts to keep them calibrated, many provide less-than-accurate readings just months after calibration. And even a slight misreading can translate into a big dollar loss. A sensor error of a single degree of temperature, for instance, can translate into a loss of 1–2 Btu per kilowatthour. Tests at one utility indicated that temperature sensors were off about 1%, for a loss of $50,000 per fossil plant annually.

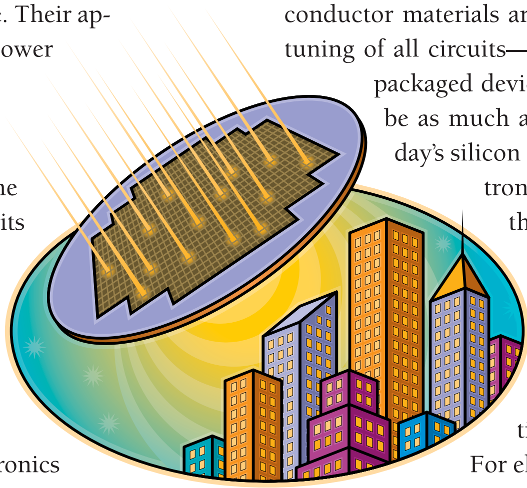
In a regulated marketplace, power companies could recoup the cost of such system inefficiencies through electricity rates. Hence that business environment provided little motivation to deploy more-sophisticated sensors. In a competitive market, however, inefficiencies will eat directly into shareholder profits. And companies that use the best sensor technologies—technologies based on optics, acoustics, microprocessors, and magnetic resonance, for example—will have a distinct advantage over their competitors.

EPRI has developed a number of advanced sensors that are ready for deployment in the power industry. To encourage their use, researchers are working to demonstrate the technologies and document their dollar savings. Meanwhile, improvements in other emerging sensor technologies continue to be made. The process is an iterative one that will result in longer equipment life and more-efficient operation. And that's just as true for a power plant as it is for a clothes dryer.

Advanced Power Electronics

Power electronics based on silicon semiconductor switching and converter devices are transforming our ability to manage the power delivery system in real time. Their application may lead to continental-scale power grids that can provide individual customers anywhere on the grid access to any electricity supplier.

Power electronics are analogous to the low-power transistors and integrated circuits that brought about the computer age, but they operate at multimegawatt power levels. They can switch electricity to a wide range of voltages, frequencies, and phases with minimal electrical loss and component wear.



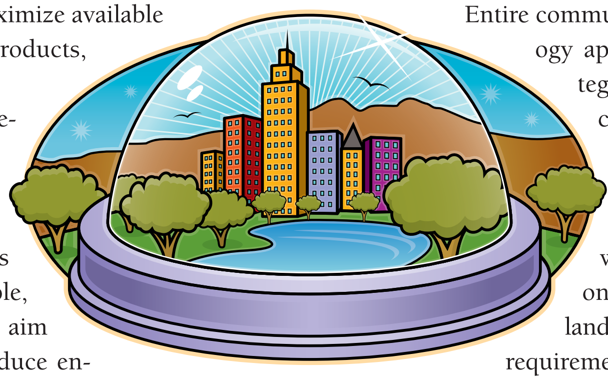
On the distribution level, power electronics are the basis for the smart, real-time control that makes it possible to meet the needs of the emerging digital economy for high power quality and customized service. In addition, power electronics are expected to make it more practical and more cost-effective to integrate distributed power sources (including renewables-based options) with the delivery system, thereby creating more market opportunities for dispersed electricity production.

Advanced high-power electronics based on new types of semiconductor materials are expected to enable precise control and tuning of all circuits—even gigawatt-scale power systems. And packaged devices made with these new materials could be as much as 100 times smaller and lighter than today's silicon devices. As a result, advanced power electronics promise unprecedented increases in the efficiency and cost-effectiveness of devices for a wide range of electricity production, delivery, and end-use applications. Such megawatt electronics are also critical for a variety of electric propulsion, control, and weapons applications for defense systems.

For electricity providers, power electronics represent the critical enabling technology for improving power system performance, offering value-added services to customers, and succeeding in a competitive marketplace. For semiconductor manufacturers, the new electronics could trigger a second electronics revolution and unlock an entirely new multibillion-dollar market.

Industrial and Urban Ecology

The disposal of by-products from industrial processes is costly, wasteful, and a drain on overall efficiency. That's why many facilities have turned to the concept of industrial ecology, reconfiguring their process flows to make productive use of their own waste streams. The idea is to maximize available resources, fully utilize industry by-products, and minimize waste.



Many industries have already implemented such process integration and recycling. Some, working with the U.S. Department of Energy, have set stretch goals for reducing emissions and solid wastes. By 2020, for example, the metal casting and glass industries aim to achieve 100% recycling and to reduce energy use by 50% and 20%, respectively. The steel industry envisions increasing its already substantial recycling by 40%.

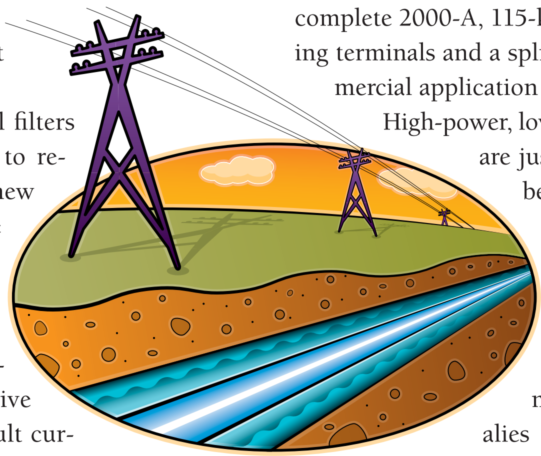
The electric power industry has also adopted challenging goals for reducing pollution. Aiming for 50% recycling by 2020, coal plants are funneling fly ash into everything from roads to concrete blocks, while sludge from plant flue gas desulfurization systems is flowing into wallboard production. Some pollution reduction efforts are taking a cue from nature. For example, constructed wetlands that mimic the cleansing processes of natural wetlands are being used to treat a variety of power plant wastewaters. Also, researchers have shown that halophytes—a diverse group of salt-tolerant plants—can remove salts and heavy metals from power plant effluents while absorbing atmospheric carbon dioxide.

Entire communities can adopt a similar, urban ecology approach to achieve efficiencies by integrating the activities of their various components—including neighborhoods, businesses, industry, and public infrastructure. The best time to begin is at the community planning stage, when all stakeholders can collaborate on an integrated approach in addressing land use, transportation, and infrastructure requirements before redevelopment occurs.

EPRI has developed a land use decision support system for urban planning that's designed to help communities identify an effective path toward sustainability. Using a Btu-based system, the methodology evaluates how efficiently we design our neighborhoods, provide housing and jobs, move people and materials, operate buildings and public infrastructure, and consume energy and other resources. The objective is to shape communities for the most efficient energy production, distribution, and use, while minimizing environmental impacts and preserving natural resources.

Superconducting Power Equipment

Thanks to recent breakthroughs in high-temperature superconducting (HTSC) materials—materials that can be cooled with liquid nitrogen—the long-standing promise of zero-resistance superconductors for utility applications could be realized in the next decade. Already, the telecommunications industry is using chip-size HTSC signal filters in cellular telephone repeater stations to reduce noise. For the power industry, the new superconductors' projected benefits are great. HTSC power cables will be capable of transmitting three to five times more current than comparable conventional underground conduits. Other superconductor-based equipment will give the grid increased protection against fault currents and lightning strikes. The new HTSC materials will also bring dramatic reductions in the size and weight of large motors and power transformers.

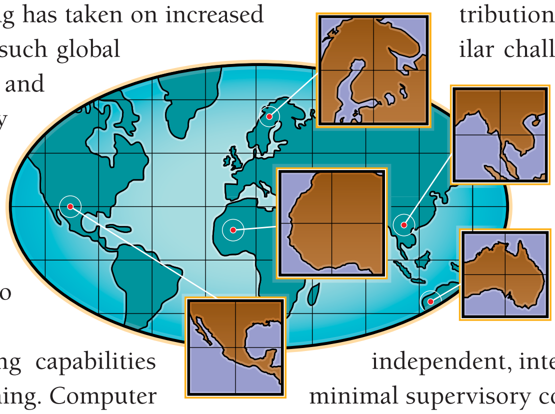


Several full-scale prototype HTSC devices have already been, or are soon to be, tested on utility power systems. Superconducting motors of 200 horsepower have been built and operated; 1000-horsepower motors are next. A 15-kV superconducting fault current limiter has been utility-tested and is nearing commercialization. This year EPRI and Pirelli Cable expect to test a complete 2000-A, 115-kV superconducting power cable (including terminals and a splice joint), which could be ready for commercial application by the year 2000.

High-power, low-energy magnetic storage systems, which are just entering commercial service and could become widespread in the next decade, are another superconductor application. Such systems can be deployed in industrial or manufacturing operations that have critical reliability requirements, enabling them to ride through momentary power interruptions or anomalies that would otherwise cause the costly shutdown of production equipment. Larger superconducting magnetic energy storage systems may eventually be used to store substantial amounts of electricity. Such systems could help utilities optimize the use of generating resources to meet peak power demand and could let system operators store bulk power for use when needed.

Large-System Predictive Modeling

Some problems are so vast that their many variables challenge even the world's most sophisticated analytical systems. One such problem is global climate modeling. As greenhouse gas emissions have become both an international and a national concern, the task of global climate modeling has taken on increased urgency. This task involves simulating such global factors as temperature, precipitation, and industrial emissions—all of which vary over time and across geographic regions. Indeed, the amount of data that must be dealt with in climate modeling is so huge that it currently takes the world's fastest supercomputers 16 days to complete a single 100-year simulation.

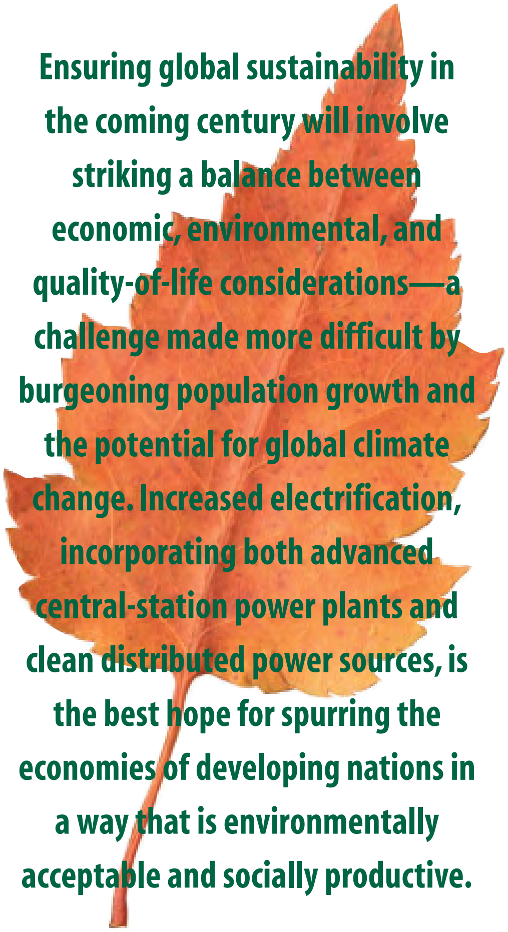


Recent advances in supercomputing capabilities hold promise for swifter number crunching. Computer speed has increased exponentially, memory is getting larger and less expensive, and software programs are now available to take advantage of the faster machines. Moreover, improvements in graphic display and electronic transfer capabilities are making it easier for climate scientists to share information in a timely manner. Soon, distributed supercomputing—the simultaneous use of supercomputers at different locations to tackle separate portions of a given problem—will be possible. This approach is critical to climate modeling, since the task is bigger than any one machine can accomplish on its own.

Modeling the North American power network, which encompasses all the transmission lines, generating units, and distribution systems on the continent, presents similar challenges. In this case, however, the aim is not to forecast far into the future but to model accurately what's happening on the network in real time. The idea is to improve the system's efficiency without diminishing its reliability. Accurate functional modeling would be an integral part of real-time, distributed control of the power system by independent, intelligent equipment operating locally with minimal supervisory control.

Because the power network in some ways resembles a living, breathing being, scientists trying to model it have turned to biological analogies to accomplish the task. One example is genetic algorithms—lines of computer code that behave much like living organisms, continually interacting with each other and mutating. As the software evolves, it rearranges itself to achieve the optimal solution to a complex problem. This and other advances being pursued hold great promise for network modeling.

Electrification and Global Sustainability



Ensuring global sustainability in the coming century will involve striking a balance between economic, environmental, and quality-of-life considerations—a challenge made more difficult by burgeoning population growth and the potential for global climate change. Increased electrification, incorporating both advanced central-station power plants and clean distributed power sources, is the best hope for spurring the economies of developing nations in a way that is environmentally acceptable and socially productive.

by Taylor Moore

A defining challenge for humanity in the next century is how to effect a progressive shift in global development toward an economically and environmentally more sustainable course. The present population of 5.8 billion people may double in the next century. The global demand for energy—a direct result of population growth and related industrialization and urbanization—is projected to double in as little as a quarter century.

Virtually all the growth in population and energy consumption is projected to occur in developing countries—home to most of the more than 2 billion people who today do not have access to electricity or other basic energy services. But if the economies and energy consumption of developing countries continue to grow in the same way the industrial and postindustrial economies of Europe, Japan, and North America grew over the past century, the global environment's adaptive capacity may be exceeded.

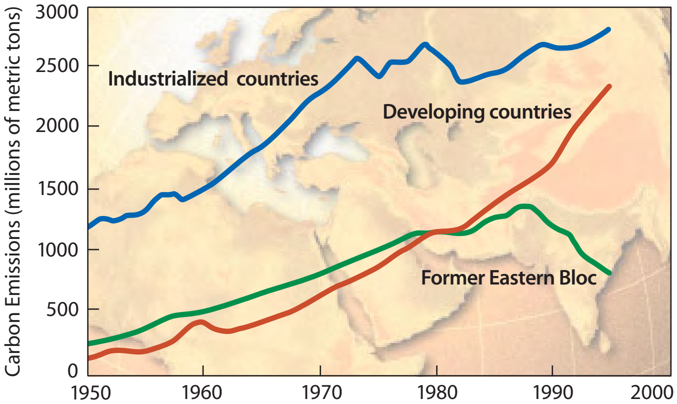
Within two decades, China—the world's most populous country—could eclipse the United States as the world's largest economy and as the largest emitter of carbon dioxide from fossil fuel combustion. India, meanwhile, could overtake China as the most populous country and could rise from its position as the fifth or sixth largest carbon emitter. Carbon dioxide and other so-called greenhouse gases trap heat in the upper atmosphere, and there is concern that increasing, unconstrained emissions of these gases over the next century could lead to global climate changes. Such changes could have uncertain, uneven, and—in some parts of the world—possibly catastrophic consequences.

Policies and actions to mitigate the risk of climate change have become, in just the past 15 years, a prominent environmental issue that will frame policy debates about energy and development well into the future. Last December in Kyoto, Japan, representatives of the United States and more than 150 other developed nations signed a treaty to limit carbon dioxide and other greenhouse gas emissions. Before the conference, the Clinton administration proposed staged reductions in U.S. greenhouse gas emissions over the next 15 years, with the goal of stabilizing them—sometime between 2008 and 2012—at levels equal to those in 1990.

But in an eleventh-hour compromise that followed 11 days of heated debate and stalled negotiations, the United States agreed to cut emissions by 7% below 1990 levels by 2012, while members of the European Union agreed to a target reduction of 8% and Japan to one of 6%.

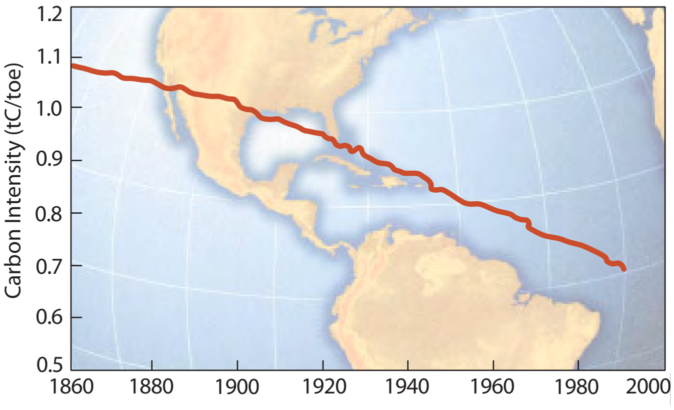
The Kyoto Protocol must be ratified by the U.S. Senate, however, which warned earlier last year in a unanimous resolution that there was no chance for approval without comparable commitments by developing countries. One concern is that draconian limits or taxes on fossil fuel emissions will stifle U.S. economic growth and drive more heavy industry and jobs to poorer countries.

Carbon Emissions: Developed and Developing Countries



Global carbon dioxide emissions from the burning of fossil fuels have nearly quadrupled since 1950. The industrialized countries are still the largest contributors, but emissions in developing countries—particularly the rapidly industrializing countries of China, Brazil, India, and Indonesia—are increasing substantially. In countries of the former Eastern Bloc, emissions have begun to level off after dramatic declines between 1990 and 1995. (Source: S. Dunn, in Starke, ed., p. 58; see the reading list at the end of this article.)

Carbon Intensity of Global Primary Energy Consumption



Worldwide, carbon emissions per unit of primary energy consumed have fallen by about 0.3% per year since 1860. (Carbon intensity is expressed in tons of carbon per ton of oil equivalent energy, or tC/toe.) The reason is the replacement of high-carbon fuels (e.g., wood and coal) by fuels with less carbon (e.g., natural gas) and also, in recent decades, by nuclear energy and hydropower—carbon-free options. (Source: N. Nakićenović, in Ausubel and Langford, eds., p. 77; see reading list.)

The U.S. negotiators at Kyoto were unable to persuade countries such as China and India to agree to limit the growth of their carbon dioxide emissions. The Clinton administration says it will not submit the treaty to the Senate for ratification until after next November's follow-up summit in Buenos Aires, at which it will try again to get the developing countries to eventually limit their emissions.

Sustainability focus

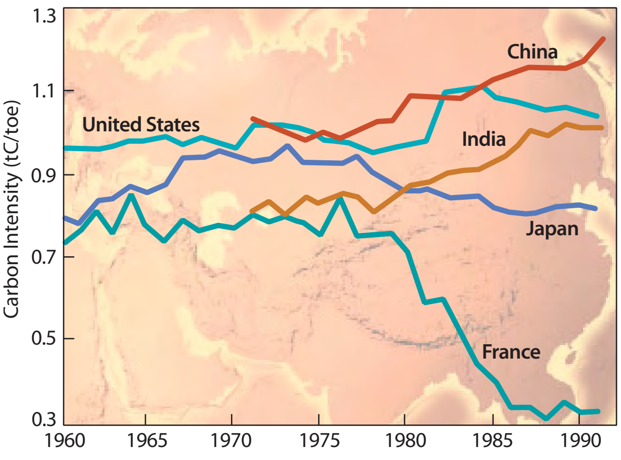
The risks and uncertainties of the greenhouse dilemma have led to a resurgence of interest in sustainable development. Distinguished from absolute economic growth, sustainable development has been defined as growth that enables the needs of the present generation to be met without compromising the ability of future generations to meet their needs. Such was the interpretation made in 1987 by the United Nations–sponsored World Commission on Environment and Development, the so-called Brundtland Commission.

The Brundtland Commission put sustainable development on the international agenda and on many national agendas. It led directly to the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, where most of the world's countries first acknowledged the risk of climate change and the need to address it. Also acknowledged were such related environmental objectives as the preservation of biodiversity and rain forests. The burning and clearing of rain forests in developing countries result in both increased carbon dioxide emissions and the destruction of wildlife habitats.

The Rio Summit produced Agenda 21, a blueprint for sustainable global development, and led to the creation of dozens of national commissions, including the President's Council on Sustainable Development in this country. It also drew responses from the professional engineering community here and abroad, including the 1992 formation of the World Engineering Partnership for Sustainable Development. A number of professional engineering organizations now include the sustainability concept among their ethical concerns.

Despite renewed interest, sustainable development is often broadly defined. The concept can be used by different people to mean very different things. At its core is the idea that ecological goods and services, the products of industry, and the benefits of a good society are all facets of

Carbon Intensity of Energy Conversion



Thanks primarily to increasing electrification, the United States, Japan, France, China, and India have all experienced a steady reduction in the carbon intensity of final energy consumption in recent decades. Only in the first three countries, however, has that reduction been accompanied by structural changes in energy systems that have led to further decarbonization—as indicated here by the downward trends in the carbon intensity of energy conversion (defined as the difference between the carbon intensities of primary energy and final energy consumption). China and India have not made a transition to less-carbon-intensive sources; because their energy systems depend heavily on coal, they are experiencing rapid increases in the carbon intensity of conversion. (Source: N. Nakićenović, in Ausubel and Langford, eds., p. 83; see reading list.)

the biosphere's support of human life. Sustainability also requires that these support functions be preserved indefinitely for future generations.

Measures of the ecological, economic, and social objectives of sustainability are sustainable scale, efficiency, and equitable distribution, respectively. Experts believe that “a truly sustainable society involves achieving sustainability in all three spheres,” notes Joseph Herkert, an assistant professor of multidisciplinary studies at North Carolina State University and a past president of the IEEE Society on Social Implications of Technology. “People generally tend to equate economic growth solely with the growth of gross domestic product, but development can also include improvements in quality of life and environmental quality. Development of this kind leaves the environment healthier.”

Herkert says that “technical people and others often view sustainable development as merely incorporating environmental issues into our thinking with the language of making explicit trade-offs between the environment and the economy. While that is desirable, the complete concept has to include the social aspects, which technical people almost by nature shy away from.”

One sustainable development option for large-scale power generation is to increase the use of low-carbon fossil fuels like natural gas. In northern Mexico, a worker surveys the site of El Paso Energy's 700-MW Samalayuca II gas-fired combined-cycle power plant, part of which is scheduled to enter service by the middle of this year.

COURTESY EL PASO ENERGY CORP.

To help meet its rapidly growing need for electricity, China is pursuing a major expansion of nuclear generating capacity. It has announced plans to increase nuclear capacity from the current 2100 MW—only 1% of the total national generating capacity—to 150,000 MW in 25 years. Eight reactors totaling 6600 MW are scheduled to join the country's three existing nuclear plants in the next five to seven years. Shown here are the two 900-MW reactors operating at the Daya Bay plant, located in southern Guangdong province near Hong Kong.

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Critical role for technology innovation

The critical role that technology plays in the way human societies are structured, consume resources, and create wastes is widely acknowledged. Some neoclassical economists argue that pessimistic views focusing on resource scarcity, such as those that became prominent during the oil embargoes and price shocks of the 1970s, result from a failure to understand the powerful interaction between technology and natural resources. That era's concerns about adequate energy supplies have since faded, for example, largely because of new technologies for finding additional reserves of oil and natural gas.

Moreover, successive technological improvements over the past century and a half have contributed to a steady, albeit slow, decline in the overall carbon intensity of the world's energy economy. “We have already begun to replace much of our coal-fired generating capacity with technologies based on natural gas, which has quite a high hydrogen-to-carbon ratio. And we expect to have options by the middle of the twenty-first century that will allow us to move more strongly away from all fossil fuels. The world is on a path to an electricity- and hydrogen-based energy economy in the coming century, if short-sighted policies don't interfere,” says Kurt Yeager, EPRI's president and CEO.

The substitutability of technology for resources is also the basis for making the world's conversion and consumption of materials, energy, and other resources more efficient and therefore more sustainable. Most visions of a sustainable future include far greater recycling of energy-intensive materials and far greater efficiency in the use of energy than yet achieved. The realization of either of these goals depends critically on technology.

Jesse Ausubel of the Rockefeller University and Robert Frosch of Harvard University, among others, have extensively documented technology's historical role and continuing potential in industrial economies to reduce the intensity of materials use, to minimize wastes, and to recycle wastes through new processes. The integration of waste minimization and treatment into process design has spawned a new field—industrial ecology.

Though its importance has drawn less attention, electrification is increasingly being acknowledged as a key element of sustainable development. The industrial growth and business development that electrification enables are synergistic—providing jobs, new opportunities for education, and other direct gains in the quality of life.

Moreover, electrification is increasingly seen as an enabling technology that can address many of the basic needs of the world's poor. It provides a way to apply efficient, advanced (low- and noncarbon) generating technologies and efficient end-use technologies that can change people's

In many developing countries, solar photovoltaic panels and wind turbines are bringing the benefits of electricity to areas where no power grid exists. Applications of these renewables-based generating technologies range from lighting and small appliances to village-scale water-pumping systems. Although the levels of power involved are small, such distributed off-grid installations can significantly improve the quality of life in remote areas.

SUSAN THORNTON/NREL

1-kW PV array with battery storage at the Orangutan Foundation International's Camp Leakey in Borneo

ROGER TAYLOR/NREL

This 50-kW hybrid system on an island off Brazil has rooftop PV panels, a small wind turbine, and battery storage.

COURTESY SOLAREX

Villagers in Oman receive television broadcasts with the help of PV power.

COURTESY SOLAREX

A South African villager follows world events on a television powered by an 83-W PV panel.

WILLIAM WALLACE/NREL

Shangdu wind farm in Inner Mongolia

COURTESY SOLAR ELECTRIC LIGHT FUND

This Chinese family in Gansu province has a residential rooftop PV module.

50-W rooftop PV panels installed in a Brazilian village under a DOE-supported project

lives in many ways. For example, the availability of electricity can make it possible for laborers to become controllers of production.

The most immediately needed applications for electricity in the developing world involve some basic elements of modern life that are taken for granted in the developed world: clean water for drinking and irrigation, public sanitation to prevent the spread of disease, and access to life-saving vaccines and medicines. Half of the world's population have no access to even minimally sanitary toilets. This lack of basic hygiene contributes greatly to the spread of new diseases, the resurgence of old ones, and the deaths of 2.2 million children a year from diarrhea and related illnesses, according to the United Nations Children's Fund, or UNICEF.

Electricity-powered motors, pumps, refrigerators, and control systems for water purification and wastewater treatment can play an essential role in solving these problems. Improved irrigation technologies powered by photovoltaics, wind turbines, or small-scale hydro, for example, could contribute to better agricultural production and thus help ease the chronic malnutrition suffered by a billion of the world's poor—a problem that, according to UNICEF, results in the deaths of 6 million to 7 million children a year.

Minimal electric lighting in homes and schools allows evening study and education that can lift people above illiteracy. By ad-

SIMON TSUO/NREL

20-W pole-mounted PV panel in Tibet

SANDIA NATIONAL LABORATORIES/COURTESY NREL

PV-powered water-pumping system in Bolivia

COURTESY SOLAREX

Rooftop PV modules power radio communications equipment and lights at a medical center in Western Samoa.

ROGER TAYLOR/NREL

dressing such needs and providing a modicum of comfort, in many developing countries the electrification of rural villages can ease economic pressures for large families and help stem the tide of urbanization, which sweeps people with little education or few skills into crowded, fetid slums.

Although not a panacea, electrification can also be a central factor in reducing the environmental degradation that typically results from the direct use of such primary fuels as wood, coal, and animal waste and such refined fuels as kerosene. The end-use technologies made possible by electricity generally serve to reduce the intensity of energy use in economic development, which in most cases means less pollution. The same is true for home life: indoor air pollution from direct fuel combustion is a near-constant affliction of 40% of the earth's inhabitants.

"Resolving the 'trilemma' among the economic aspirations of a rapidly expanding global population, the available resources, and the environment is, I believe, the critical challenge of global sustainability and the defining challenge of the twenty-first century," says Yeager. "The marriage of electricity and innovation is the essential vehicle for resolving this global challenge, and we must actively confront the barriers that prevent innovation from flowing into those parts of the world that need it most."

Balancing growth and the environment

According to an EPRI initiative called the Electricity Technology Roadmap, the level of per capita electricity consumption necessary for rising above subsistence and making even marginal economic progress is about 1500 kWh per year. This level would represent, on average, a fourfold increase in electricity consumption for some 60% of the world's population and would require at least a thousand, and perhaps several thousand, gigawatts of new generating capacity. Still, it is less than 20% of the average per capita consumption in the United States, western Europe, and Japan. The capital requirement to meet just the energy demand of global growth is almost $2 trillion a decade.

Again, the central challenge is to strike a balance between environmental conservation, economic development, and growth in living standards, particularly in the developing world. A business-as-usual pattern of development is increasingly seen as unsustainable in the long term, both because of the economic risks posed by the potential for climate change and because of the inequitable distribution of energy resources and the benefits of development.

Low-cost power is essential for industrial development. This need traditionally has been met through the use of low-cost, high-carbon indigenous fuels, such as coal and oil, and low-cost, inefficient generating equipment. Moreover, most economic development has served mainly to improve the quality of life for urban populations, bypassing rural societies. Together these difficulties imply the need both for cleaner, more-efficient central power plants and for distributed generation.

There appears to be an emerging consensus that the widespread deployment of distributed, off-grid, renewables-based generating technologies could be very important in accelerating the advance of electrification into most of the developing world now lacking power grids and delivery infrastructures. The technologies include photovoltaics for home rooftops, farm- or village-scale microhydro, wind turbines, and biomass-fueled heat and power generators.

The capital-intensive nature of large-scale generation and delivery infrastructure development can make high-cost distributed technologies a cheaper alternative in many cases in developing countries, especially considering the small amounts of power typically needed in rural settings. The same can be true even for remote loads in the United States, but the need for remote power sources is far greater in the developing world.

"It's amazing what a big difference a small amount of energy can make for people," says Laurie Stone, an engineer with Solar Energy International, a Colorado nonprofit organization that provides training and technical assistance for renewables-based rural electrification projects in Latin American and other developing countries (see sidebar, p. 50). "To most of us, 50 watts of power—which can be supplied by one rooftop photovoltaic module—represents enough power for a lightbulb. But 50 watts can significantly change people's lives by enabling them to read or study at night, or sew without damaging their vision, or live healthier and longer because refrigeration systems give them access to vaccines. Most of us take these things for granted."

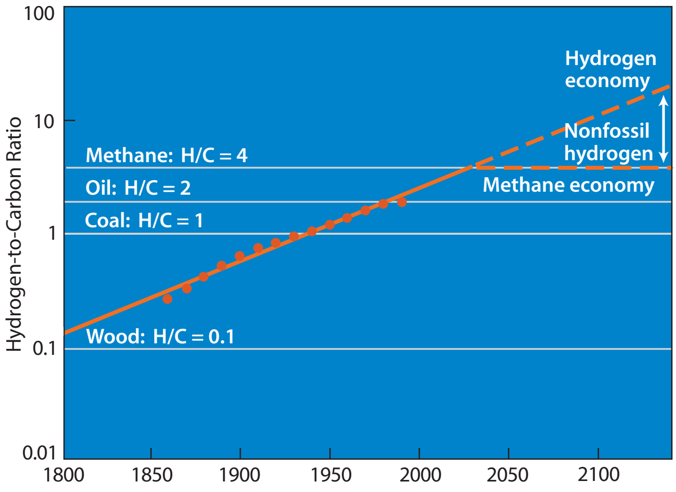
While distributed, off-grid generating technologies could play a major role in improving the quality of life for many poor people in developing countries, even more important for national economic expansion is large-scale power development, including central-station generating plants and interconnected delivery grids. This importance is evidenced by the planning and construction of hundreds of gigawatts of new generating capacity now under way throughout the developing world. The economic growth and rising personal income that large-scale electrification can make possible also have the positive effect of reducing population growth.

The cities of the developing world are replete with opportunities for upgrading the efficiency and environmental performance of existing central generating plants and distribution systems. In a growing number of these cities, substantial expansion of energy infrastructures is needed to support burgeoning populations.

"By 2020, there will be more than 30 cities in the developing world with populations greater than 10 million, and a new one will be added every year or two thereafter. These rapidly growing megacities all lack the essential infrastructure capabilities to support the influx of new arrivals," notes Kurt Yeager. "Typically, the dominant energy forms in these cities are not electricity and natural gas but kerosene and charcoal. The rising temperature of the human climate that results from poverty and hopelessness should occupy more of our collective attention as we enter a new century."

With adequate financing from international development institutions and private capital, the developing world could provide critical mass markets for emerging high-efficiency technologies like fuel cells and biomass gasification for combined-cycle cogeneration. It could also provide fertile markets for high-efficiency clean coal technologies, such as integrated gasification–combined-cycle generation.

Hydrogen-to-Carbon Ratio for Global Primary Energy Consumption



A slow but steady move toward the use of higher-grade fossil fuels has been the key element of global decarbonization over the last 200 years. The current growing dependence on natural gas (methane), which has four atoms of hydrogen for each atom of carbon, is expected to continue through the middle of the next century. After that, nuclear, renewable, or other, as yet undeveloped, nonfossil generation options are likely to take precedence, possibly leading to a hydrogen energy economy by the century's end. (Source: C. Marchetti, "Nuclear Plants and Nuclear Niches," *Nuclear Science and Engineering,* Vol. 90, No. 4 [August 1985], pp. 521–526.)

Incentives for no-regrets actions

Increasingly, analysts see the large-scale deployment of renewable energy technologies in the developing world as a key element of a no-regrets strategy for mitigating the risks of global climate change. Combined with major efforts by developed countries to make their production and consumption of energy—especially electricity—20% to 30% more efficient, a greater use of renewables can lead to win-win strategies for sustainable development. Not only can such strategies provide immediate environmental and economic benefits in both poorer and richer countries, but they can also result in significant reductions in carbon dioxide emissions.

A cornerstone of the Clinton administration's proposed program for achieving U.S. commitments under the Kyoto treaty is a five-year, $6 billion series of tax credits and research subsidies to encourage energy conservation. Another is an international system of tradable greenhouse gas emissions permits, similar to the permit-trading system already being used by U.S. utilities and industry to cut sulfur dioxide emissions. Companies could get extra credit for voluntary, early steps to limit greenhouse gas emissions, including investments to reduce emissions in developing countries. Such foreign investments are expected to be far more cost-effective than efforts to attain a comparable level of emissions reduction in this country, and from a global perspective the emissions results would be the same.

Several electric utilities have reacted positively to the tradable emissions permit elements of the administration's program. "The electric utility industry believes flexible compliance measures, including international emissions trading and global joint implementation with credit, are vital components of any program to control greenhouse gas emissions," says E. Linn Draper, chairman and CEO of American Electric Power.

AEP and PacifiCorp—along with British Petroleum, the Nature Conservancy, and a Bolivian environmental organization—are pioneering a joint implementation project for carbon sequestration. The project's goal is to protect 5 million acres (representing 58 million metric tons of carbon dioxide) of tropical forests from logging for 30 years. This effort is one of 26 joint implementation pilot projects that utilities have undertaken in cooperation with the U.S. government to sequester carbon dioxide or to reduce or avoid its emission.

According to Stephen Peck, EPRI's vice president for environment, the Clinton administration's policy proposals that seek to pursue the least-cost options worldwide for reducing carbon emissions are consistent with EPRI-sponsored analyses, including those produced by the Stanford University Energy Modeling Forum under Professor Alan Manne and EPRI's Richard Richels. They and others have argued that market-based incentives can more effectively limit greenhouse gas emissions at a fraction of the cost of traditional, command-and-control environmental regulations.

But similar suggestions for flexibility in the timing of emissions reductions, aimed at more efficiently spreading the costs of ultimately stabilizing atmospheric concentrations of carbon dioxide, were not part of the administration's proposals, says Peck. A flexible approach in terms of both where and when emissions reductions are achieved would yield the optimal, least-cost path, according to some analysts.

"An approach that promises to reduce the cost of containment by 90% is certainly worth a try," says Richels. "There are strong reasons for preferring emissions strategies involving modest reductions in the near term, followed by sharper reductions later on. Time is needed to adapt the industrial capital equipment stock, for example. Low-cost, low- and noncarbon energy alternatives now under development are apt to be more plentiful in the future. And even if the cost of removing a ton of carbon were the same over time, the discount rate still favors deferred reductions."

Whatever the emissions reduction timetable is, there is little disagreement that the development and application of no-regrets (more-efficient, less-carbon-intensive) technologies should be accelerated. "There are advanced technologies already on the shelf that can help us dramatically increase the efficiency of energy end use and can reduce sharply the emissions of carbon dioxide from energy supply," Harvard University professor John Holdren told a White House conference on climate change last October.

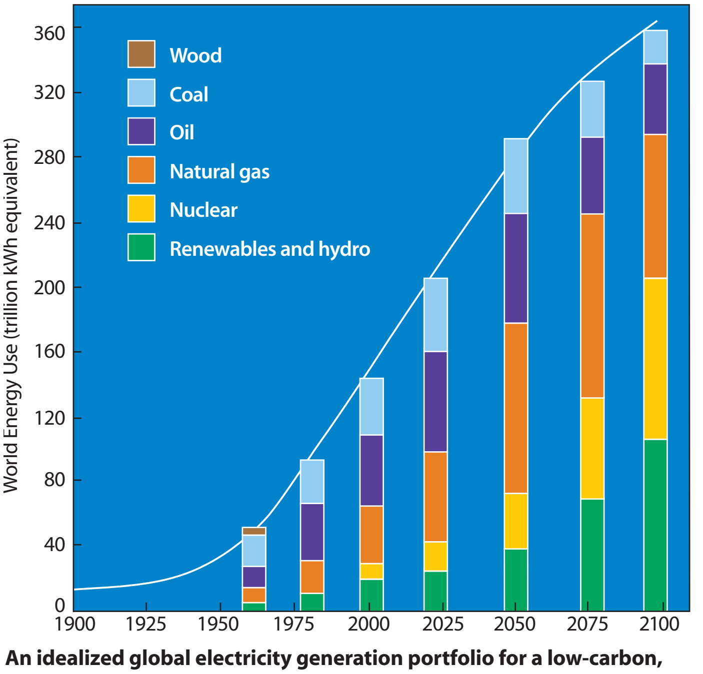
"We need only some sensible attention to reducing the barriers to the more rapid and widespread diffusion of these advanced technologies," said Holdren, an expert in energy and environmental science who has advised the Clinton administration on climate policy. "There are new technologies that can be brought to the point of applicability with expanded research and development that would make increased energy efficiency and reduced carbon emissions even more cost-effective."

Similar calls for expanded support for R&D include one from the President's Committee of Advisors on Science and Technology. This high-level, private-sector group, which advises both the president and the National Science and Technology Council, has noted the importance of science and technology to sustainable economic development and environmental stewardship in the face of growing world population and energy demand.

A study performed for the U.S. Department of Energy by five national laboratories last September also saw a need for greater national investment in energy efficiency and clean energy technologies—options that hold much promise for a range of applications, from more-fuel-efficient, zero-emission vehicles to more-energy-efficient buildings and industrial manufacturing. Biomass and biofuel, energy-saving appliances, and advanced natural gas turbines for high-efficiency combined-cycle generation were identified as critical technologies for minimizing the costs of reducing carbon emissions.

The DOE study concluded that the near-term energy savings from such technologies would cover their cost. Some

Future Generation Portfolio



An idealized global electricity generation portfolio for a low-carbon, hydrogen-based energy economy would entail much greater use of renewable resources and nuclear power to make up for a declining fossil fuel contribution. Advanced technologies and industrial ecology would lead to greater energy conservation as well as to greater efficiency in converting primary energy to electricity.

Sustainability Success Stories Abound

Literally thousands of individual success stories of sustainable development, particularly efforts involving rural electrification, can be found all around the world, according to published articles and information available on the Internet. Yet also clearly evident are the potential and the need to replicate each success story millions of times over.

There are substantial government-sponsored technology transfer programs and demonstration projects, including those of the U.S. Department of Energy's National Renewable Energy Laboratory, the U.S. Agency for International Development, and such multilateral development organizations as the World Bank (through its Global Environment Facility, or GEF). In a $30 million photovoltaic market initiative in India, Morocco, and Kenya, for example, the GEF is investing in consortiums that offer both grid-connected and off-grid PV systems for various applications. In addition, dozens of nongovernmental organizations and nonprofit groups are directly engaged in bringing the benefits of solar electricity to people in the developing world.

COURTESY SOLAR ELECTRIC LIGHT FUND

A PV module powers lights and a radio inside the tent of this Tibetan family.

Education and training in the installation and use of renewables-based technologies for rural electrification are critical to long-term success. Since 1991, over 700 people from 31 countries have received practical classroom and hands-on training in a renewable energy education program run by Solar Energy International (SEI). Under contract with the Pan American Health Organization—part of the United Nations' World Health Organization (WHO)—SEI has trained technicians in Colombia, Brazil, the Dominican Republic, Honduras, and Peru in the installation, maintenance, and repair of PV-powered systems for vaccine refrigeration. Similar efforts are starting up in Nicaragua and Mexico. Over 350 solar-powered refrigerators have been installed in remote village health clinics in Peru alone, and nearly 200 have been installed in the Dominican Republic.

Ken Olson, SEI's executive director, says that the compact, high-efficiency refrigerators meet WHO specifications to maintain vaccines between 0 and 8°C and to freeze ice packs, which are then used in coolers to enable vaccines to be transported for up to two days without refrigeration. This WHO program, which is called Cold Chain, manages the distribution of vaccines, and ensures their quality, in much of the world.

In Colombia, the Pan American Health Organization and the Dutch government collaborated in a project to electrify a health center, enabling it to have fluorescent lighting, a video theater, and a battery-charging operation. The theater shows health and hygiene videos for free and generates income from modest fees charged for movies, news, and sports events. "The lighting helps support literacy education and also could be used for income-producing activities, and being able to charge batteries helps us provide some home lighting in the community," says Olson. "Literacy and better education are important to disease prevention, and PV lighting is a good alternative to kerosene lamps, which cause many accidents and injuries."

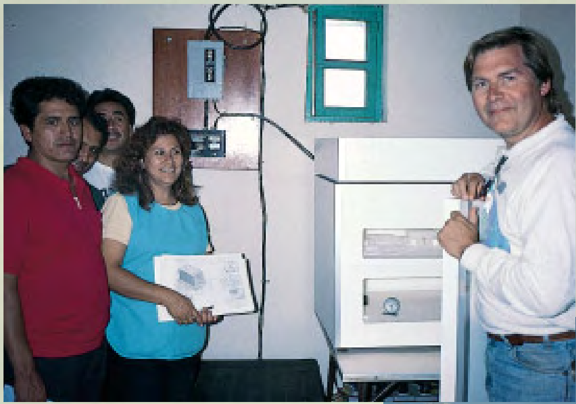
Innovative financing arrangements that enable poor people to pay for solar or other renewables-based technologies are vital for the success of rural electrification. The Solar Electric Light Fund (SELF), a nonprofit charitable organization based in Washington, D.C., has helped finance and broker the purchase and installation of hundreds of solar home lighting systems in pilot projects in Brazil, China, India, Indonesia, the Solomon Islands, South Africa, Sri Lanka, Nepal, Tanzania, Uganda, and Vietnam.

COURTESY SOLAR ELECTRIC LIGHT FUND

Zulu women technicians install a rooftop solar panel in South Africa.

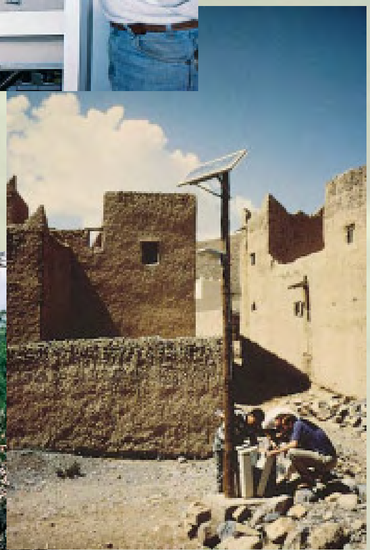
A typical 50-W rooftop or pole-mounted module can charge a battery that can power two compact fluorescent lanterns, as well as a small television or radio, for a few hours in the evening. It can also be used to charge batteries for a cellular telephone. The home PV system costs around $500. It is estimated that such a system, used as a replacement for kerosene lamps, could displace an average of 6 tons of carbon dioxide per household over its projected 20-year life.

But even $500 is prohibitively expensive for poor people. To bridge the financing gap, SELF and other organizations underwrite the costs with government or World Bank grant funds and work with established local groups or with groups set up specifically for the projects. The local groups do system installation and servicing and administer payment systems by which households can repay the costs, with interest, in small increments over several years. "The payments go into a revolving local fund that can be used to finance installations for other fami-lies, and eventually a project becomes self-sustaining," says Bob Freling, SELF's executive director. Such revolving-credit funds have been set up to finance home PV systems in Vietnam, China's Gansu province, and the Indian states of Andhra Pradesh and Karnataka.



KEN OLSON/SOLAR ENERGY INTERNATIONAL

This PV-powered vaccine refrigerator in a remote Peruvian health clinic is one of hundreds installed in Latin America.



COURTESY SUNLIGHT POWER INTERNATIONAL

PV modules are being used in Morocco for village streetlights and residential rooftop applications.

COURTESY SOLAR ELECTRIC LIGHT FUND

This solar thatched-roof home is in the Solomon Islands.

In another effort—one made possible by $2.5 million in private equity from European investors—SELF launched a commercial energy services company to install and service solar home lighting in developing countries around the world. And with World Bank funding, SELF is working with a local organization to electrify 2200 homes in Sri Lanka.

"We've focused on creating commercially viable financing vehicles so that private capital could eventually flow in and expand the scale of installations," says Freling. "We're just scratching the surface, but we've shown in pilot projects in various countries that there is willingness and ability to pay for these solar home systems. And because these wireless power systems, if you will, also make it possible to introduce wireless communications, they are providing customers with a way to plug into the world without having to plug into a power grid.

"We don't pay cash up front for things like cars and homes—and certainly not for electric service. Why should it be any different in a developing country? Poor people traditionally have not had access to credit. But a decade ago, institutions like the Grameen Bank of Bangladesh began pioneering the use of microcredit to address the needs of the poor, and it is now a growing trend."

A for-profit company—SunLight Power International, also based in Washington, D.C.—is pursuing projects, markets, and financing arrangements similar to those being pursued by SELF, but entirely with private capital. For a modest monthly fee that includes a return on investment, SunLight Power leases rooftop solar systems to customers and provides guaranteed service packages for maintenance, repair, and access to upgrades. Locally managed service centers also serve as revenue collection points and as a home base for marketing and sales.

Toward its goal of providing solar service to one million customers, SunLight Power has raised over $5 million in equity capital for business development and is seeking to raise $45 million more over the next seven years. Two of its investors, insurance companies based in Germany and in Switzerland, were motivated by self-interest to mitigate the long-term business risks of global climate change.

Initially, SunLight Power is focused on developing operations in five countries. In the Dominican Republic and Honduras, it is teamed up with SOLUZ, Inc., a fee-for-service pioneer. Several hundred households in Morocco are also getting solar home power systems in a current project, and the company is planning operations in South Africa and China.

Among many other notable rural electrification campaigns, 25,000 households in Kenya have purchased unsubsidized PV systems from domestic suppliers that provide minimal power for the equivalent of 25¢ per kilowatthour. And in Indonesia, the Australian government is funding a $25 million project to supply over 36,000 rural homes with solar home systems within three years. □

energy economists dispute the claim, however, and argue that the cost of emissions cutbacks could amount to $50 per ton of carbon, causing a significant negative impact on electricity costs and wiping out potential savings.

Still, according to Florentin Krause, a former staff scientist at Lawrence Berkeley National Laboratory, there is great potential for achieving significant cost reductions in many carbon-free, renewable energy technologies, including wind and photovoltaics, both through more-aggressive R&D and through market-creating technology transfer efforts in developing countries. Krause, who initiated the International Project for Sustainable Energy Paths in 1986, says that "rural electrification in developing countries represents enormous market-creation potential for renewables. Through such development, a broad set of societal and global goals for advancing electrification would be directly linked with a potential for technology cost reductions that would also benefit our domestic economy and global competitiveness.

"The developing world is where technological development can find the largest market and where the dynamization of energy and technology export for the United States is potentially the greatest by far. Orienting our development focus to those in greatest need can help bring about the cost reductions in technologies that the whole world needs in order to deal with the risk of climate change."

HERMES JUSTINIANO/FUNDACIÓN AMIGOS DE LA NATURALEZA

A joint implementation project to preserve, for 30 years, nearly 5 million acres of tropical forests in and around Bolivia's Noel Kempff Mercado National Park is being pursued by American Electric Power, the Nature Conservancy, Fundación Amigos de la Naturaleza, BP America, and PacifiCorp. The project aims to sequester some 58 million tons of carbon dioxide and to promote economic development in local communities.

An evolving view of sustainability

Many companies in the energy industries have already begun to respond to the challenge of global sustainability. Under DOE's Climate Challenge program, for example, more than 100 U.S. electric utilities have signed accords or commitments detailing a variety of measures they are taking to limit carbon emissions or sequester carbon in the next few years. The initiatives cover a broad range, including support for zero-emission vehicles, energy storage, forestry management, distribution automation, renewable energy, demand-side management, cogeneration, recycling, and repowering.

Last fall, weeks before the Kyoto Summit, British Petroleum announced plans to institute a carbon emissions reduction program entailing an internal, company-wide system of emissions trading. "The oil industry has the ability and the responsibility both to contribute to the debate on the design of policy instruments and to take a leadership position by showing that we can make a constructive contribution to the solution," says John Browne, BP's chief executive. "The world needs oil and gas in growing volumes. But the people of the world have to be convinced that their needs can be met without destructive consequences."

Nuclear power—despite distinct economic, political, and environmental difficulties—may become increasingly attractive in the next several decades, its proponents say, if the world is serious about decarbonizing the global energy economy. U.S. nuclear plants prevented the cumulative emission of some 2 billion metric tons of carbon dioxide over the past quarter century, they note. Lessening the risks of climate change may require some explicit trade-offs with the risks associated with nuclear power.

According to José Goldemberg, a professor at the University of São Paulo who has served as Brazil's secretary of state for science and technology and as its secretary of the environment, "The simplistic idea that energy conservation and the enhanced use of renewables could solve the world's sustainability and environmental problems, particularly those of developing countries, in the next few decades is unrealistic. All sources of energy will be needed, despite energy conservation efforts in less-developed countries and industrialized countries.

"The alternative for developing countries would be to remain at a dismally low level of development, which, ironically, would generate more deforestation, land degradation, and an unchecked population growth that would aggravate the problems of sustainability. Development can indeed be the cause of serious environmental problems, but so is underdevelopment, particularly at the local level.

"A delicate balance between economic paralysis, with its grievous consequences, and development has to be sought," concludes Goldemberg. "Ways will have to be found to promote development while minimizing, but not completely avoiding, environmental problems." ■

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