Piecing Together the Electric Vehicle

ELECTRIC POWER RESEARCH INSTITUTE

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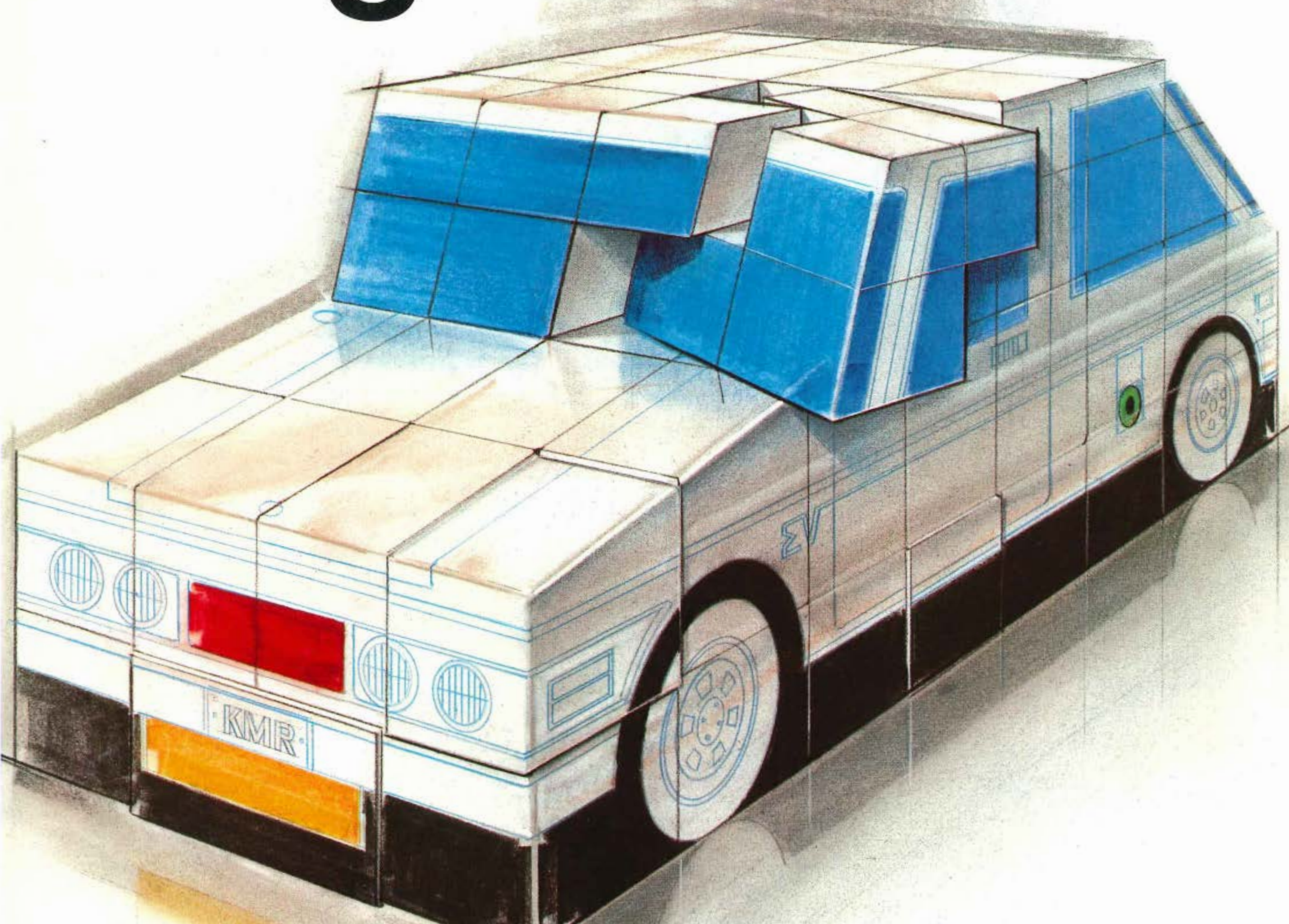

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Cover: The electric vehicle can be seen as a puzzle within a puzzle. A better battery is not enough to ensure widespread use. Parallel developments must be made in all pieces of the transportation infrastructure.

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Electric Vehicles: Still an Open Question

Consider these developments of the last few years. Programs to develop and demonstrate capable EVs have sprouted in most of the highly industrialized countries of the world. Congress has asked DOE to carry forward a $160 million program to develop EVs and accelerate their commercial introduction. The U.S. Postal Service is about to purchase several hundred more EVs for mail delivery because of the favorable experience with its first 350. General Electric Co. and Chrysler Corp. have teamed up to develop a sleek EV prototype that is said to have a range of 70 miles under stop-and-go conditions, a 55-mph cruising speed, and the potential to be mass-produced for about $6,400. The president of General Motors Corp. has stated publicly that GM plans to produce and sell EVs in the mid-1980s.

Do these and other recent developments herald the advent of EVs as a broadly accepted mode of transportation? Perhaps. No definitive answer to this intriguing question is presently possible. Clearly, the EV has several significant limitations. Even if some of these can be overcome in time, the economic and logistic hurdles involved in making a major shift in an institution as pervasive as the automobile are formidable. This month's lead article explores some of these limitations and hurdles and, in doing so, develops perspective on the likely capabilities and possible impact of electric vehicles. It makes several key points:

- Even today's imperfect EVs can perform a number of useful jobs, but to date their role has been limited and their impact minimal.

- If they find widespread use, EVs could materially reduce our dependence on oil, and they could significantly reduce environmental pollution in urban areas.

- It is possible to think about and pursue several technological avenues that could help bring about the broader use and societal benefits expected of EVs.

At the same time our present assessment must leave open several very important questions. How far can we expect to push the capabilities of batteries and, consequently, the range, performance, and general appeal of EVs? To what extent can we improve all the other functional parts of EVs, while reducing their cost? What are the potential markets, the eventual oil savings, and the resource conservation impacts of EVs that have different capabilities? What impact will a growing population of EVs have on the distribution, transmission, and generation capabilities of electric utilities? What can the major parties involved—the automotive and electric equipment industries, federal and state governments, the electric utility industry, and, of course, the potential users—do in the critical years ahead to more fully realize the potential of EVs?

The answers can only come from vigorous programs to assess, develop, demonstrate, and if appropriate, commercialize EVs and the supporting energy and service systems. The electric utilities, and EPRI with them, can play a key part in the required national effort, and plans for different levels of involvement are just now being formulated at EPRI and reviewed with supporting utilities. Although these plans are not yet fully detailed, I see emerging an important role for EPRI, working closely with utilities, industry, and government, in improving the technologies and creating the conditions that will help EVs become a nationally significant response to key energy and environmental problems.

Fritz R. Kalhammer

Fritz Kalhammer, Director
Energy Management and Utilization Division

Authors and Articles

How social attitudes influence U.S. patterns of energy development and use is evident in the *Journal* articles this month. But equally evident are the more tangible issues of economics and technology that shape the specific targets of applied research.

Take electric vehicles, for example. Attitude is quickly apparent. In this sprawling nation of suburbs and widely scattered towns, can we or will we revise the value we now put on private automobile range, performance, and convenience?

In the lead article, **The Promise and Puzzle of Electric Vehicles** (page 6), Mary Wayne surveys the energy, transportation, and environmental incentives for EVs; the major issues of battery technology; and the implications of EV use for utility generating capacity, load shapes, and system performance. Short of a fuel emergency that pushes all economic considerations aside, our automobile value perception is one controlling factor in the future of EVs. But the other factor is something that hard technology tells us right now: Without a battery breakthrough that no one expects, EVs simply won't be functionally interchangeable with today's Ford LTD, Dodge van, or VW Rabbit. Either EVs will serve a more limited role than today's car or the nation will have to develop a convenient and pervasive system for recharging.

Three EPRI research managers contributed their knowledge and insight to Wayne's report: Fritz Kalhammer, director of the Energy Management and Utilization Division; Ralph Ferraro, Kalhammer's technical manager for electrical interface and control systems; and Anthony Lawrence, project manager in the Demand and Conservation Program of the Energy Analysis and Environment Division.

Kalhammer has headed EPRI's work in energy management since November 1973, when he organized Institute research programs in electrochemical energy conversion and energy storage. Earlier, he was with SRI International for 12 years, investigating fuel cells and batteries and as manager of the SRI electrochemistry program. Kalhammer earned BS and MS degrees in physics and a PhD in physical chemistry at the University of Munich.

Ralph Ferraro has specialized in power systems for 20 years. Before coming to EPRI in December 1977, he was control systems engineering supervisor for Bechtel Power Corp., involved in the design of power plant controls and instrumentation. In earlier work with General Dynamics Corp. and Regulators, Inc., he was chief engineer for the design and production of control systems used in a variety of military, industrial, and commercial power units. At EPRI, Ferraro has research responsibilities in the controls for fuel cells, load-leveling batteries, EV batteries, MHD power generation, and superconducting magnet energy storage. He is a 1965 electrical engineering graduate of the Newark College of Engineering, New Jersey.

Anthony Lawrence came to EPRI in August 1975 and almost immediately undertook economic research in EVs—their potential cost, performance characteristics, and customer acceptance—and in transportation systems, such as electrified highways. His analyses of time-of-day and seasonal energy demand patterns have also recognized the possible influences of electrified transportation alternatives. Lawrence previously was an assistant professor of economics at the University of Kentucky and a research economist for the U.S. Bureau of Labor Statistics. He holds BS, MS, and PhD degrees in economics from the State University of New York at Buffalo.

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Synthetic fuels from coal have been all the rage—and also the target of rage—at the national planning and legislative level for the past several months. How badly do we want or need them and what are their implications for the overall economy and environment? Apart from these questions and the value perceptions that underlie their many answers, the subject poses its own intriguing question, **Synthetic Fuels Cheaper Than Oil?** (page 18).

Three EPRI technical staffers recently analyzed this question and came up with a positive answer, plus several all-important assumptions that determine *whether* and several financial incentives that determine *when*. *Journal* feature editor Ralph Whitaker drew on their analysis and on EPRI observations about the steps in technology development that ultimately control synthetic fuel commercialization.

The analysis of synfuel price incentives was prepared by Dwain Spencer, Bert Louks, and Michael Gluckman of the Advanced Power Systems Division. Spencer joined EPRI in April 1974 to manage solar and geothermal energy research programs, later became division technical manager, and is now director of the Advanced Power Systems Division Earlier, he worked with the Jet Propulsion Laboratory of the California Institute of Technology for 16 years, moving through various space systems design responsibilities to the management of space technology applications in several professional and commercial fields and then to a special assignment with the National Science Foundation as manager of its solar-thermal energy conversion program. Spencer is a Notre Dame chemical engineering graduate and earned an MS in nuclear engineering at Purdue University.

Bert Louks came to EPRI in October 1973 from SRI International, where he had worked for six years as an engineering economist in energy resource development and application. He returned to SRI International in July 1975 as director of industrial and utility energy systems, then rejoined EPRI in March 1977. He is now project manager for novel power cycles. Louks's earlier work, particularly during eight years with Union Oil Co. of California and four years with Pacific Delta Gas, Inc., included chemical process R&D, petroleum and gas production planning and marketing, venture analysis, investment planning, and process plant economic analysis. Louks is a 1950 chemical engineering graduate of the University of Missouri.

Michael Gluckman heads the engineering and economics evaluation program of Spencer's division. Before joining EPRI in September 1975, he was an associate professor of chemical engineering for four years at City College of the City University of New York. Earlier, he was a process engineer with St. Regis Paper Co. for nine years. Gluckman holds BS and PhD degrees in chemical engineering from the University of Cape Town (South Africa) and the City University of New York.

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Ferraro Kalhammer

Louks Spencer Gluckman

The shrill whine and shattering booms of supersonic jets generated noisy nationwide debate that led to the demise of the SST. The routine energetic hum of utility transformers has aroused fewer voices perhaps, but the annoyance and complaint are just as real. Unlike the SST, however, technology has quietly produced solutions. Steel and plastic are the stuff of tuned enclosures that selectively attenuate unwanted audio frequencies. Nadine Lihach, *Journal* feature writer, tells how utilities are **Tuning Out Transformer Noise** (page 24). Edward Norton, manager of transformer research projects in the Transmission Department of EPRI's Electrical Systems Division, provided the technical background.

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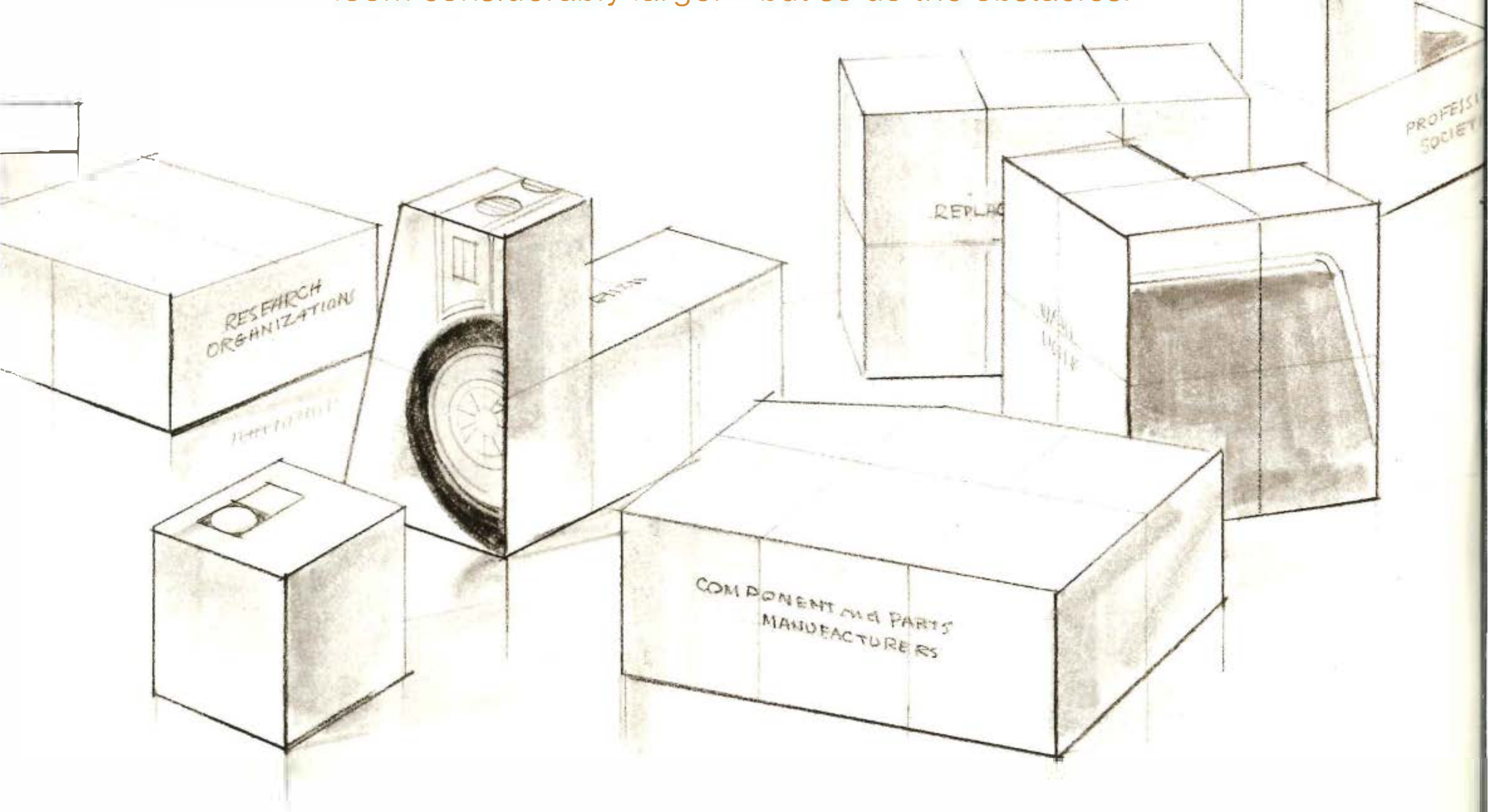
When we look at the entire economic fabric of a nation, such threads as energy use, labor productivity, capital formation, industry composition, area, population, culture, and climate are interwoven to form a distinct pattern. And every national tapestry is different. Yet efforts to single out and compare only those threads pertaining to energy use lead critics to ask severely, **Does the United States Waste Energy?** (page 26).

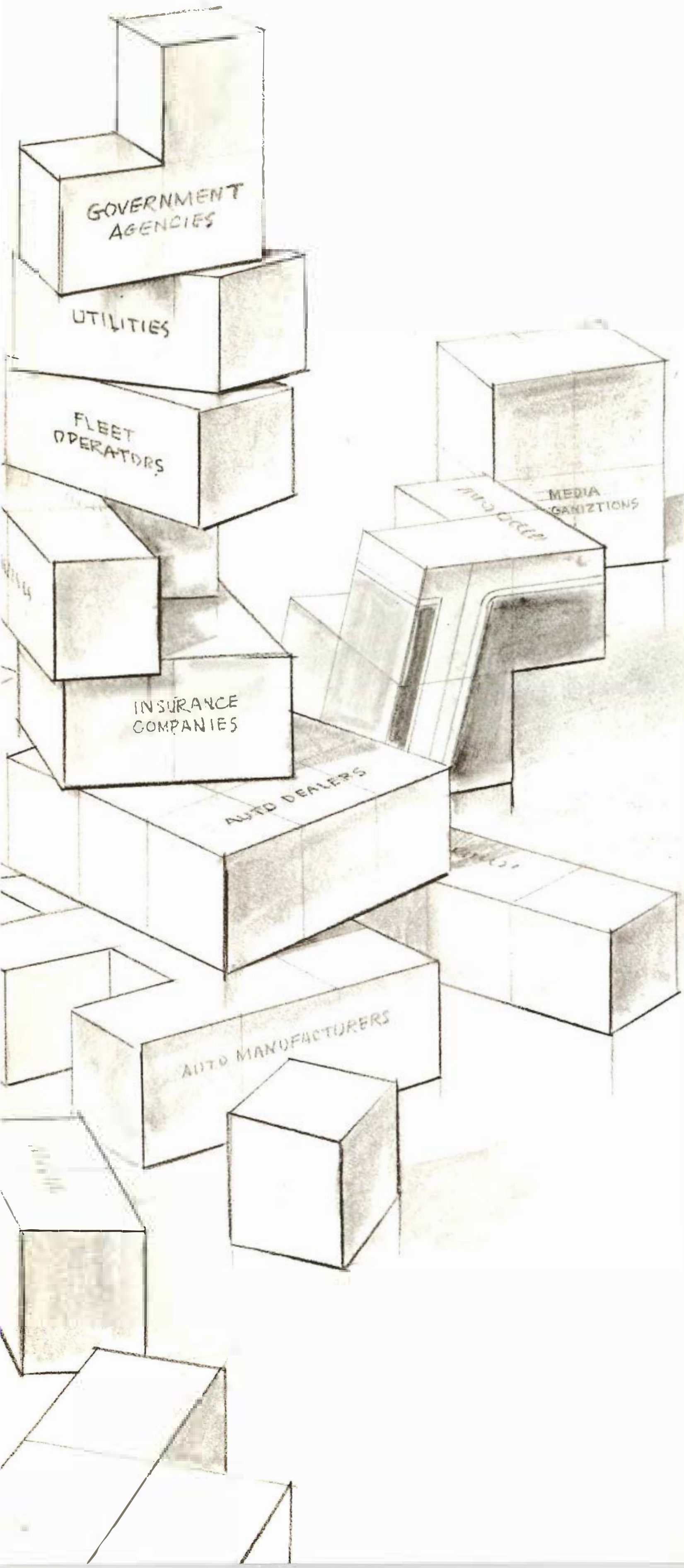
As an answer, *Journal* feature writer Jenny Hopkinson interprets our own and other economies to explain their inherent distinctions and the inevitability that energy use is part of a far larger pattern. It is difficult to say that any one national pattern is best and probably impossible to reweave the threads of the U.S. economy to match it.

Hopkinson developed her article with the aid of C. F. Anderson, an economist in the Special Studies Department of EPRI's Policy Planning Division since July 1976. Anderson has concentrated on econometric analysis, all the way from individual company market studies to international economic comparisons, during a 14-year span that includes affiliations with McDonnell Douglas Corp.; Systems Associates, Inc.; Pacific Architects & Engineers, Inc.; The Ralph M. Parsons Co.; and SRI International. He has also held numerous teaching and lecturing positions with the University of California, Fresno State and San Jose State universities, and Loyola University (Los Angeles). Anderson earned BA and MA degrees in economics at the University of California at Santa Barbara.

The Promise and Puzzle of Electric Vehicles

Dormant for half a century, the electric vehicle (EV) is being revived. The prospect of slashing oil dependence and urban pollution in tandem is enough to inspire hope and stimulate large-scale research into such technical problems as batteries. But even here success will not be enough. Mass production and widespread use of EVs will require thoughtful development of every element in the transportation infrastructure—from energy delivery to parts manufacture to service, maintenance, and insurance. How it will all be put together is an open question. No one has yet written the assembly instructions for complete systems integration. This time around, the social benefits of EVs loom considerably larger—but so do the obstacles.





Invented in the 1880s, the electric vehicle (EV) soon emerged as a bright, new alternative to the horse-drawn buggy. By 1904 an estimated one-third of all the vehicles in Boston, New York, and Chicago were electrics.

But just as the battery-powered EV was gaining the spotlight, it was muscled offstage by an even more exciting performer, the internal combustion vehicle (ICV). The ICV, propelled by its so-called explosion engine, could outperform the EV in so many ways that consumers rushed to trade in their electrics, and the manufacture of these vehicles all but stopped.

Today, the internal combustion car can still outperform the electric, but EVs are getting a long second look.

Why the renaissance?

EVs are edging toward the spotlight again because they offer certain energy, environmental, and transportation benefits that conventional cars do not. Their biggest asset is that they don't use gasoline. In Henry Ford's day, oilfield bonanzas fueled the popularity of the then-new motorcar. Now all that has changed, with fuel prices climbing and oil supplies threatening to dry up.

Today, the energy promise of EVs begins with two basic facts: About half the oil we use is for transportation, and about half the oil we use is imported. Putting these two facts together suggests a conclusion: Switching from oil to electricity for transport power could wipe out our need for imports.

Even the most ardent EV enthusiasts see snags in this simple equation, however. For a start, it is highly unlikely that electricity can replace all our petroleum-based fuel needs because electric batteries store so much less energy for a given weight or volume than do fuel tanks. Electricity probably won't replace diesel fuel for long-distance trucking, nor will it replace jet fuel for the nation's air fleet. Generally, whenever vehicles must cover appreciable distances over varying routes, chemical fuels—derived from oil now, from coal and biomass in the longer term—will be more convenient and versatile sources of transportation energy.

Transportation in the United States consumes about 8 million barrels of oil every day. If only 25% of the miles driven in conventional vehicles were driven in electrics instead, it would save about 2 million barrels daily, totaling a yearly cutback of more than 700 million barrels. To put this figure in perspective, it represents more oil than all the nation's electric utilities burn in one year.

In the long run, with more specialization of vehicles for different transportation modes, a much higher level of substitution appears possible, particularly when we consider the full range of potential vehicle electrification. If all the vehicles that could run on batteries rather than liquid fuels—city buses, light trucks, light vans, and passenger cars used for short-distance driving—were actually to convert, about 70% of the oil used in the transportation sector might eventually be replaced by electricity.

Another big reason for interest in EVs (and the main reason prior to the gasoline crunch) is the fact that electrified transport can help preserve the environment. The internal combustion engine is known to be responsible for much of our urban smog. Air quality modeling in 24 urban areas has shown that a full switch to EVs should slash polluting hydrocarbon and carbon monoxide emissions just about in half. EVs could glide almost silently through the canyons of our big cities, leaving no exhaust trails in their wake.

Coal power plants that produce much of the electricity to run these cars have emissions of their own, of course. Prime among these are sulfur oxides from fossil fuel plants, emissions that could increase by perhaps 20% if all passenger cars were electrified. But it is both more efficient and cheaper to control air pollution at a relatively few stationary sources than at millions of mobile sources. Nuclear power plants, of course, would not have any of these emissions, not even carbon dioxide. Combining these two technologies could make a long-range contribution by containing any problems associated with the rising levels of carbon dioxide. So the net effect of vehicle electrification would still be cleaner air, especially in those traffic-clogged cities that need it most.

Further, EVs could offer unique transportation benefits. Being more compatible with automated-vehicle operation and control, EVs would capture many of the strong points of mass-transit schemes without sacrificing the comfort and convenience of the private car. Centrally controlled automation, besides reducing high-speed collisions and banishing traffic snarls, could move more vehicles through a narrower corridor, saving many acres of land that would otherwise be gobbled up by an ever-expanding freeway system.

This, then, is what a massive switch to EVs could do. But there is no assurance that such a switch will actually take place. Turning from future possibilities to present realities, we need to look at some of the obstacles that may determine whether or not EVs can make it on their second chance.

Operating experience

So far, there are only about 3000 EVs on American roads. And with the exception of a handful owned by futurists and technology buffs, almost all belong to experimental programs.

The U.S. Postal Service runs the largest program and operates about 350 EVs nationwide, although most are in California. With a daily range of only 20 miles and a top speed of 33 mph, these vehicles would hardly meet the needs of the average motorist, but they have done well in filling the more limited and specialized role of postal route vehicles. Operating problems have dropped from 1.5 failures for conventional vehicles per month to only 0.4 for EVs, and the Postal Service plans to enlarge its fleet with several hundred more electrics in the months ahead.

Other nations are also forging ahead with EV use. Great Britain, where driving distances are shorter and where gasoline traditionally costs at least twice as much as it does in the United States, is the historical leader in vehicle electrification. Upwards of 40,000 British EVs regularly deliver mail, milk, and other commodities, functioning mostly as route vehicles for local, low-speed stop-and-go driving.

West German vehicle manufacturers and electric utilities now have several joint research ventures in progress, including some novel arrangements for vehicle recharging. France is experimenting with electric buses, and Fiat is developing electric vans in Italy. The Japanese, working through a well-coordinated government and industry program, have been pushing ahead with vehicle design and battery research. Tokyo, Kobe, and Osaka operate battery-powered buses in public transport service.

But even on a worldwide scale, current use of EVs remains minimal, and it is limited almost entirely to fleet operations: commercial route vehicles and public transport. Is this sort of use enough to make a dent in the oil consumption problem?

For the United States, probably not. The majority of the nation's roughly 150 million vehicles are private cars. And the immediate market for electric route vehicles comes to no more than a few hundred thousand a year. Even adding the market for electrified public buses fails to approach the penetration level (perhaps some tens of millions) necessary to reduce oil imports.

So it appears the long-term target for EV commercialization will have to be the private passenger car. And here is where serious doubts arise. Can the American consumer ever be persuaded to give up the cherished gas guzzler, or even the compact, for an electric car that will, in all likelihood, offer more limited performance at a higher purchase price?

The first question for a wary consumer eyeing the EV is the obvious one: Will it work? The answer is yes, for certain uses. Even the EV built today can perform quite well in local driving, such as short trips to work, to school, to shopping malls, or to the supermarket. And the U.S. Department of Transportation estimates that 90% of the average motorist's driving falls into this short-trip category (20 miles or less).

But an EV won't take you on your summer vacation. Current models can only go about 20–40 miles before they have to stop for gradual, hours-long recharging. Adding to this range problem is the EV's leisurely pace. Most of them can't go faster than 40–55 mph, and if maintained, that top speed will drain the batteries more rapidly than driving at a low, constant speed.

Poor acceleration is another drawback. Current electric vehicles take 10–20 seconds to struggle from 0 to 30 mph. Because this could be a traffic hazard in high-speed areas, it's best to stay off the freeways. And many EVs don't take hills very well, either. Finally, cold weather and battery aging can add to these problems by further depressing battery performance.

The battery dilemma

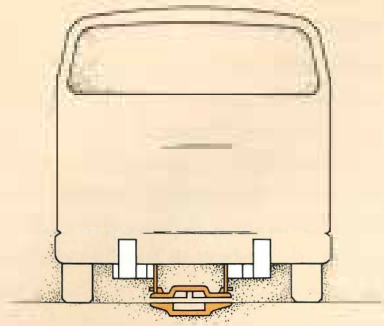
Today's EV runs on massive banks of lead-acid batteries, most of them of the type used in modern golf carts and not very different from the batteries used in the turn-of-the-century electrics. Many an EV advocate sees more efficient batteries as the only cure for the vehicle's shortcomings.

ELECTRICS THE SECOND TIME AROUND

Overwhelming competition from the internal combustion vehicle forced the first wave of battery-powered electrics off the road by the end of the First World War. Developmental activity in electric passenger vehicles was effectively shelved, and research emphasis shifted in the next half century to more specialized roles: service vans, fork lifts, and golf carts. With the petroleum shortages of the 1970s, R&D activity had a resurgence, foreshadowing a second wave of passenger electrics. Styling changes aside, the electric vehicle has advanced little from its predecessor 60 years ago.

Shown in contrast: an EV being recharged during a promotional run from Seattle to Mount Rainier in 1919; a Henney Kilowatt TVA demonstration car of the 1960s; and an EV destined for 1985 and beyond. The last was developed for DOE by General Electric Research and Development Center and Chrysler Corp. Powered by 18 high-energy-density lead acid batteries, the test vehicle is expected to achieve a range in excess of 100 miles.

ELECTRIFIED HIGHWAYS



Electrified highways sound so futuristic that we might regard them as a fantasy reserved for the year 2000 and beyond. But research is already under way to open up this method for recharging EVs while they are actually in motion.

The concept is simple. A charged metal coil about 2 feet wide and only 1½ inches deep, encased in a protective cover to prevent shocks to people or animals crossing the road, would be laid directly on top of a line on the highway. The coil would be flush with the pavement and would be marked so EV drivers could easily locate it. No tearing up or trenching of the highway would be necessary. Nor would the coil have to be continuous, because EVs could store electricity and run for a number of miles between electrified stretches.

A power collection device on the underside of each vehicle would be inductively coupled to the conducting coil in the roadway, meaning that the electromagnetic field set up by the coil would be converted to alternating current on the vehicle. No direct contact would occur. An air gap of roughly 1–2 inches would exist between the vehicle's power pickup device and the road. Icing could interfere with charge transfer during the winter months, but natural heat loss from the charged coil is expected to warm the road and help keep the electrified strip ice-free.

Howard R. Ross Associates notes that with in-motion recharging, the EV could actually far surpass the ICV in range. "If the U.S. interstate system is electrified in this fashion," states their recent report on future transit systems, "one could drive from San Francisco to New York without stopping to recharge."

The technical suitability of any battery for EV use hinges on two measures: energy density (the ratio of usable energy to battery weight) and cycle life (the number of times a battery can be charged and recharged before it wears out).

What limits the range of current EVs is the low energy density of the lead-acid battery, which typically is only 27–33 Wh/kg (12–15 Wh/lb). At this level, extending EV range to about 100 miles would require more than 2 tons of lead-acid batteries because today's vehicles need between 0.5 and 1.5 kWh a mile.

Building lead-acid batteries with thinner electrode plates could reduce weight and thus improve energy density, but thinner plates wear out more quickly. Thicker plates have better cycle life, but this merely aggravates the weight problem. So the potential of the lead-acid battery, while not yet fully exploited, appears limited by the conflicting requirements of energy density and cycle life.

Because of these limitations, battery research is trying new electrochemical combinations: nickel-iron, nickel-zinc, zinc-chlorine, and others. A nickel-zinc battery, for example, may be able to deliver the same usable energy as the lead-acid battery at less than half the weight, which would effectively double the energy density. Short cycle life and high cost still restrain this battery hope, although recent work at GM indicates potential for a solution.

More advanced possibilities, such as the sodium-sulfur and lithium-iron sulfide batteries, promise even better energy density. Here the major snag is high operating temperature, on the order of 300–450°C (570–840°F), a feature that could intensify safety problems under recharging or collision conditions. Overall, what shows up in a scan of battery prospects over the next few years is a series of trade-offs as researchers try to improve battery characteristics in some areas without sacrificing too much in others.

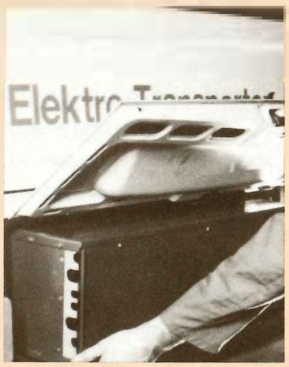
Range: the fundamental limitation

Improving energy density is a primary target of battery research because it means extending range. And range, according to Fritz Kalhammer, director of EPRI research on EV technology, is "the most fundamental limitation" in making an electric car acceptable to a broad cross section of the American public.

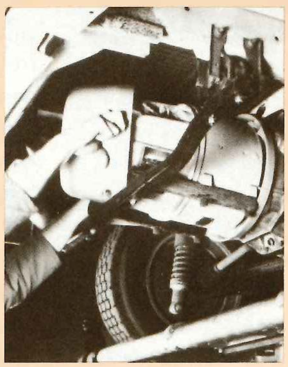
Anthony Lawrence, who manages Institute studies on the EV's economic aspects, concurs, adding that the range problem is really a problem of waiting. Americans don't like to wait, which is a major reason why they prefer private cars to public transportation. Enduring long recharging layovers would be even worse than standing at a bus stop or sitting in a gasoline line.

Reports abound of electric test cars that have run for 100 miles or more on a single charge, but that doesn't mean the 100-mile EV is here in any practical sense. Test models are often stripped down to compensate for the weight of the lead-acid batteries, a move that increases range but can run afoul of safety standards. The range of EVs driven at a constant speed under ideal weather conditions is in no way typical of what the

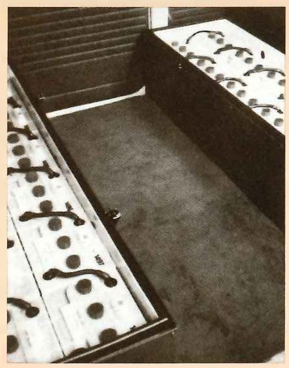
EPRI's 8-passenger Volkswagen electric bus, presently undergoing a two-year demonstration at TVA in Chattanooga, is shown with its major propulsion system components.



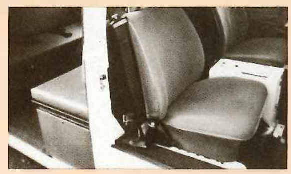
Acceleration is adjusted by the electronic controller, which dictates the voltage and current delivered to the dc motor.



The dc traction motor is coupled to the vehicle's rear axle through a fixed-ratio gearbox. Without gearshifting, the motor can accelerate the vehicle to a maximum speed of 70 km/h (44 mi/h).



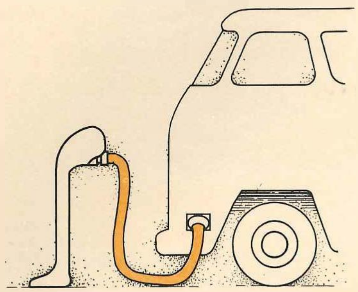
The 144-V traction battery is composed of twenty-four 6-V lead acid batteries in series. Battery maintenance is readily accommodated by lifting the bench seatcovers.



The on-board battery charger system can recharge the traction battery in 8–10 hours from any convenient 208/220-V ac outlet.

The vehicle is equipped with a receptacle plug for charging the traction battery.

BIBERONNAGE



Biberonnage, French for "bottle-feeding," has a special meaning in transportation. It is a method of extending EV range by feeding the vehicle electricity from recharging outlets whenever an EV needs a pickup to keep its battery charged.

Besides being used for overnight recharging in the owner's home garage, the method would be adapted for recharging at the places most cars spend their days—in the parking lots of offices, factories, and shopping centers. The driver would simply park the car and plug it into an outlet. The car's battery would be recharged automatically while the driver went about his or her business.

There are questions, of course. Would the outlets be coin-operated? If not, who would pay for the electricity provided to motorists? Would the responsibility fall to employers and shopping-mall operators, to all the ratepayers in a service area, or to taxpayers under some public financing scheme? Related to these questions is the matter of who would be responsible for installing and maintaining such a network.

Developing a longer-range battery that would make such recharging unnecessary may cost hundreds of millions of dollars and require a decade for commercialization. For much less money, large numbers of charging outlets could be established at workplaces and shopping malls, making even today's limited-range EV a viable transportation alternative.

average motorist would get in stop-and-go driving under real-world weather and traffic conditions.

The challenge of boosting real range has inspired several quite different efforts toward a solution. There is the drive to achieve a breakthrough in battery technology. But Kalhammer cautions against placing too much faith in this prospect. "The probability that we are going to develop a battery that will give us a 100-mile range or more on a single charge at reasonable cost is not very high, less than 50%," he estimates. "Even if we succeed in developing advanced batteries with greater energy density than the lead-acid, cost rather than weight is likely to limit the amount of storage capacity we can afford to carry in an electric vehicle. This doesn't mean we shouldn't look vigorously for more-capable and less-expensive batteries. But we should not tie the mass development of EVs absolutely to batteries with capabilities far beyond the lead-acid battery."

Setting aside a battery breakthrough, what other options are there for extending range and moving ahead with EV commercialization? The possibilities are varied: a massive network of public recharging outlets, electrified highways, greater emphasis on hybrid vehicles, battery exchange, and a whole reassessment of our current system of privately owned automobiles, to name some of the most discussed.

Public recharging networks and electrified highways are both intriguing schemes. The concept of a hybrid vehicle (one with a small engine in addition to an electric drive powered by batteries) is straightforward, and some prototypes already exist. For short trips, a hybrid would operate on batteries alone. The engine would take over on longer trips, boosted occasionally by the electric motor for acceleration and help in climbing hills. Increased cost and complexity would be the drawbacks, plus the fact that hybrids wouldn't save as much petroleum as all-electric vehicles.

The idea of pulling into a battery-switching station may seem far-fetched, given the size and weight of current battery banks, but proper equipment for carrying out the switch could help make this a viable option. A bigger problem would be capital cost. The battery represents a major part of an EV's price tag, and keeping an adequate inventory of vehicle-size batteries would require a substantial investment, as would the forklifts and other special machinery needed to accomplish a safe, rapid battery transfer. Experimental stations already exist for electric buses in Düsseldorf, West Germany, but the complexities and cost of such an operation make it unlikely that stations will pop up on every street corner to service private passenger cars.

More remote still is the possibility that Americans would be willing to switch cars entirely when the battery charge ran out. The idea of maintaining a public system of exchangeable EVs might work in theory, but in practice it would challenge the intensely personal relationship that many Americans have with their cars. Who would pay for these public EVs, and who would maintain them? Furthermore, who would mastermind their deployment in all the proper places?

None of these alternatives for range

BATTERY PROSPECTS—EV APPLICATION

Battery Type	Temperature (°C; °F)		Energy Density (Wh/kg; Wh/lb)		Power Density (W/kg; W/lb)		Estimated Cycle Life (charges)	Estimated Cost ($/kWh)	Estimated Availability (year)
Lead-acid	Ambient		40	18	70	32	>1000	70	1982
Nickel-iron	Ambient		55	25	100	45	>2000	100	1983
Nickel-zinc	Ambient		75	34	120	55	>500	100	1982
Zinc-chlorine	30–50	85–120	90	41	90	41	>1000	75	1985
Sodium-sulfur	300–350	570–660	90	41	100	45	>1000	75	1985
Lithium-iron sulfide	400–450	750–840	100	45	100	45	>1000	80	1985

extension is problem-free. The reason for considering them is that they could make the difference between success and failure in commercializing the electric vehicle on a significant scale without waiting for a miraculous breakthrough in battery technology.

Can EVs compete in cost?

Another key question for prospective purchasers: Can the EV compete economically with the conventional car?

When making cost comparisons with an eye to the EV's commercial future, several facts need to be borne in mind. One is that today's EV is really an abstraction. There is no mass-produced EV on the market. There are only limited-production experimental models of various capabilities, most of them converted from conventional cars and some of them hand-built, one-of-a-kind prototypes. This means they lack the engineering refinement and volume cost savings available in mass-produced, conventional cars.

Even with mass production of at least 100,000 vehicles a year, an EV would still cost more than a comparable ICV. The 25–40% premium would represent the cost of the battery bank itself because the cost of all other functional parts (the electric component system versus the internal combustion system, for example) would just about balance out. A $6000 EV, then, would be comparable to a conventional car priced roughly in the $4500 range (1979 dollars). To be economically competitive, the EV must make up for this higher price tag by offering lower operating and maintenance costs.

Let's look at the EV's prospects in this area, beginning with the price of fuel. Electricity is already somewhat cheaper than gasoline as vehicle fuel (perhaps 2–4¢ versus 3–6¢ per vehicle mile). It is likely that this gap will widen as gasoline prices increase and/or liquid synthetic fuels made from coal appear on the transport market.

The economic viability of coal-based fuels is actually a source of vigorous debate. Some say that converting coal into synthetic gasoline rather than electricity is the logical choice because it would relieve our oil dependency without the big changes that a switch to EVs might entail. Others point out that synfuels will cost more than gasoline and far more than electricity per vehicle mile once the as-yet-unknown environmental cleanup costs tied to synfuels are factored in.

To save 50,000 barrels of oil a day, we would have to spend an estimated $1–$2 billion on synfuel production but only $0.5–$1.5 billion on building and recharging EVs, according to recent studies at Purdue University. Another option to use coal for transportation energy—production of utility-grade synfuels for use in power plants that supply EVs—also appears more efficient and cheaper than the large-scale production of synfuels for direct use in automobiles. If fuel cost is the criterion, then, the days of the ICV may dwindle as the supply of natural oil dwindles, and the advent of the EV may be only a matter of time.

Reliable data on comparative EV–ICV operating costs are sparse and available mostly for light commercial vehicles. Long Island Lighting Company (Lilco) reports an operating cost of only 2.4¢ a mile for its electric route vehicles, using off-peak storage rates plus fuel adjustment. In contrast, a standard vehicle averaging 15 mpg at 90¢ a gallon costs about 6¢ a mile to operate. This comparison does not include the cost of EV battery replacement, however, which could add substantially to the lifetime operating expense of the vehicle.

Routine EV maintenance is expected to pose few problems. An EV has fewer parts to break down or need replacement because of wear. It has no starter, spark plugs, distributor, fuel pump, carburetor, pistons, valves, water pump, radiator, muffler, oil filter, or pollution control device. With tuneups abolished and expensive repairs held to a minimum, the EV owner could look forward to substantially lower maintenance costs than the owner of a conventional car.

Federal commercialization program

The EV, as a fledgling technology, faces market competition with the mature ICV. To succeed, the EV needs all the help it can get. Because the market risks/capital costs of this undertaking are so great and because the commercialization of EVs could help so much in solving our energy problems, the federal government is playing a major role in supporting such a move.

The genesis of the federal EV program is the Electric Hybrid Vehicle Research, Development, and Demonstration Act (P.L. 94-413) passed by Congress in 1976. This act provides funds to conduct research on improving EV performance, to support demonstration programs designed to acquaint the public with EVs and show that they can work, and for loans to potential EV manufacturers. The initial price tag is $160 million for the first five years.

Federal research focus falls mainly on new batteries and improved vehicle technology. Batteries that show a potential for rapid improvement and early availability are the first target. Private contractors are now at work on upgraded lead-acid batteries, nickel-iron batteries, and nickel-zinc batteries to be delivered for federal testing by the end of 1981.

Originally, 7500 vehicles were to participate in the demonstration phase of the federal program. Now that number has been boosted to 10,000. So far, only a few dozen of the lead-acid test cars are actually on the road, but DOE hopes to have 2000–3000 in operation by 1982 and 10,000 by 1985.

Private sector EV demonstrations actually began several years before the federal effort, with the Electric Vehicle Council's plan that placed more than 100 battery-powered vans in use at about 60 electric utilities across the United States and Canada. Now, in addition, the federal program has experimental electric vans for AT&T's coin-telephone repair crews in New York City and electric service cars for Lilco's meter readers on Long Island. In what is expected to be a trend-setting move, Lilco has posted special low nighttime rates for EV users. From midnight to 7 a.m., the recharging rate is only 1.73¢/kWh, less than half the utility's normal rate.

Despite a promising start, the DOE demonstration program could be running into trouble. In spring 1979 the General Accounting Office (GAO) issued a report raising questions as to whether the demonstrations will really win public acceptance for EVs. Given the current EV's problems with reliability, safety, performance, and cost, cautioned the report, the program could backfire.

The program "may be placing vehicles in uncontrolled situations where any such failures will be highly visible and could damage public acceptance of more advanced vehicles when they become available," according to GAO. Rather than muddying the waters with uncontrolled demonstrations in the private sector, the report recommends confining the test vehicles to the federal sector for the immediate future.

Other government efforts to spur EV commercialization zero in on economic incentives. For example, a bill is now before Congress to offer a 10% tax credit, up to $1000, to consumers who buy EVs or convert their conventional cars to electrics. Similar tax breaks for prospective EV manufacturers would help reduce the risk of unsuccessful forays into the marketplace and provide an incentive to take on the huge capital investment required to begin mass production. Furnishing a guaranteed market by buying an estimated 300,000–500,000 vehicles for government use might be another federal move that could help spur commercialization of EVs.

Retooling of auto parts manufacture and assembly lines to mass-produce EVs would be a huge adjustment, but important legislation now before Congress could make it worthwhile. Auto manufacturers are under the gun to make their new cars more fuel-efficient: an average of 27.5 mph by 1985, according to the government's corporate average fuel economy (CAFE) standards. The proposed amendment would allow manufacturers to count the gasoline-equivalent mileage of any EVs they produce in meeting those efficiency standards.

Including EVs in the CAFE standards could hike their potential market penetration by as much as 40%, according to some observers. DOE has pegged 8.6 million vehicles as a likely figure for EVs in the year 2000. But with the CAFE incentive, DOE estimates that figure could jump to 12 million, a number that crosses the threshold to significant market penetration.

GM REPORTS BATTERY PROGRESS

On Tuesday, September 25, General Motors Corp. reported that its zinc-nickel oxide battery, under development for several years, now promises to meet the company's performance standards for use in electric vehicles. Weighing about one-third less than existing lead-acid batteries, the new battery is expected to store roughly twice the energy and last for more than 20,000 miles of driving.

Meeting these expectations doesn't guarantee GM's entry into mass production of electric vehicles, however. Battery cost remains a big question, as does integrating the perspective battery into a suitable overall design for the vehicle itself. As GM President Elliott M. Estes acknowledges, it will take more time and more studies before we know for sure whether the nation's number one auto maker is really going into the EV business.

Complementing the federal program

EPRI's own work in EV R&D is designed to complement the federal effort by focusing on those aspects of commercialization that would be most important for the energy supplier, the nation's electric utilities. As the energy supplier, utilities could play a significant role in the commercialization of EVs, says Jerry Mader, EPRI project manager for electric transportation. Initially, it will be important for utilities to understand the effects of this potential new load on the utility system. For example, impact on utility feeder distribution systems and load curves could appear locally first and then spread to a national scale. This means that utility-oriented EV research needs to take a careful look at what will be required in the way of efficient battery recharging and electric power availability in order to support any widespread shift to EVs.

EPRI is now conducting a small, closely controlled two-year pilot demonstration at the Tennessee Valley Authority (TVA) to learn more about how EVs work in a real-world environment. Preliminary tests at Southern California Edison Co. have permitted the selection of 10 Volkswagen electrics (5 vans and 5 microbuses) to undergo more intensive evaluation at TVA. Central to vehicle choice was the idea that test EVs should be standard models with reliable manufacturer backup, models that would be viable candidates for future upgrading and eventual mass production.

These 10 vehicles (and another 10 to be selected later) will be used for van pooling, small delivery, and service and maintenance trips in the Chattanooga area. In the words of Ralph Ferraro, EPRI technical manager for electrical integration, the point of the monitoring effort is "to build a real-world data base to focus research, design, development, and demonstration efforts for future EVs.

"Until we observe exactly what current lead-acid batteries can and cannot do in service applications, for example, there is no way of telling what real progress is being made in battery technology. Until we discover how operating costs stack up, we won't have adequate information to determine where to concentrate in making the EV economically competitive. Until we see whether the charger, for example, can charge the battery without disrupting the rest of the electric network, we are unable to fully define how well the components of an EV system function together. And until we know what sort of infrastructure EVs need to keep operating (recharging facilities, service, and so on), we cannot fully evaluate the costs of EVs or their impact on the electric utility industry and other industries."

In the Energy Analysis Department, EPRI economists are looking at electric vehicles as a potential load impact. Both the level and the pattern of electricity demand will be important. Will there be enough EVs to create a significant new load for electric utilities? If so, how will that load be distributed? Will EVs aggravate peak-load problems with daytime recharging?

The first and biggest question is how many EVs there are going to be. "Once we have an idea of the total number involved," says Lawrence, "figuring out their load impact will be fairly easy."

It will be fairly easy, that is, if one accepts three basic assumptions common in the field. The first is that EVs will replace ICVs on a one-to-one basis, rather than representing an entirely new market, such as the market for mopeds, which often supplement the ICVs in a household rather than replace them. The second is that motorists will maintain roughly the same short-distance driving patterns in EVs that they have in ICVs, rather than creating entirely new patterns, such as the weather-dependent patterns of the moped. Third, most EV recharging will take place at night, during off-peak hours.

Because the critical target for EV market penetration is the private passenger car, finding ways to project future demand in this sector is a top priority. Contractors Charles River Associates Inc. and the University of California at Berkeley are currently exploring the market for EVs and the consequent impact on electric utilities, building on an earlier EV demand model developed for EPRI by Mathtech, Inc. And Howard R. Ross Associates is examining electricity needs for future transportation systems as a whole.

Economist Lawrence believes that electric transportation systems could conceivably replace the ICV for private passenger use by the year 2000, just as the jet engine has replaced the piston engine for air travel in a similarly brief span. But the prospects for such a change, he emphasizes, must be considered in the broader context of the nation's priorities, present and future. What role will transportation systems play in future lifestyles? How important will environmental issues of noise and air pollution be? What about the huge investment that oil companies and their dealers have in existing motor transport? Will Congress subsidize displacement of oil by EVs?

EV contingencies

Anyone seriously contemplating the future of electric vehicles is left with a bundle of ifs. If petroleum grows increasingly scarce and expensive; if synthetic liquid fuels prove too polluting or too costly to replace petroleum-based fuels; if ICV technology fails to achieve a major breakthrough in fuel efficiency; if we succeed in extending EV range, either through battery advances or special recharging arrangements; if air quality and noise laws grow tougher; and if the large infrastructures required to support such a change can be put in place rapidly, with a high degree of cooperation between government, industry, and consumers, then the EV could indeed be the car of the future.

The hurdles are very real, but so is the promise. The EV can relieve major problems that have emerged since its abortive debut many decades ago. Today's America has needs that yesterday's America did not. So the time may finally be ripe to embrace the unique advantages that the EV has to offer. ■

Balzhiser

Saxe

Balzhiser and Saxe Named to Senio

Two vice presidents have been elected by the EPRI Board of Directors. Richard E. Balzhiser is vice president for research and development, and David Saxe is vice president for finance and operations. Both officers report to EPRI President Floyd L. Culler.

Balzhiser, who assumes responsibility for management of EPRI's technical programs, has served as director of the Institute's Fossil Fuel and Advanced Systems Division.

Saxe moves into a comparable position and is responsible for the Institute's finance and administrative functions. He has served as director of the Administration Division.

"The establishment of this new executive level within EPRI significantly strengthens our management abilities," Culler said in making the recent announcement. "As EPRI moves out of its formative years and its R&D program matures and expands, the need for more direct management of its day-to-day operations becomes apparent. These and other moves put us in a strong position to carry out our responsibilities to the industry in the years ahead."

Before joining EPRI in 1973, Balzhiser was assistant director of the White House Office of Science and Technology. Earlier, he was chairman of the Chemical Engineering Department at the University of Michigan.

Saxe came to EPRI in 1973 with over 25 years of experience in the administration of research activities at the Atomic Energy Commission and Rockwell International Corp. At Rockwell he was vice president for operations of the Atomics International Division.

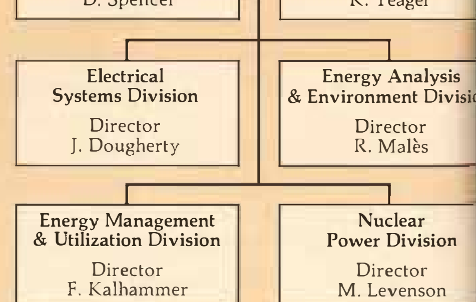
Further appointments

In related moves, EPRI's Fossil Fuel and Advanced Systems Division has been divided into three new technical divisions that will report to Balzhiser. Culler announced the appointment of the following new directors: Fritz Kalhammer, Energy Management and Utilization Division; Dwain Spencer, Advanced Power Systems Division; and Kurt Yeager, Coal Combustion Systems Division.

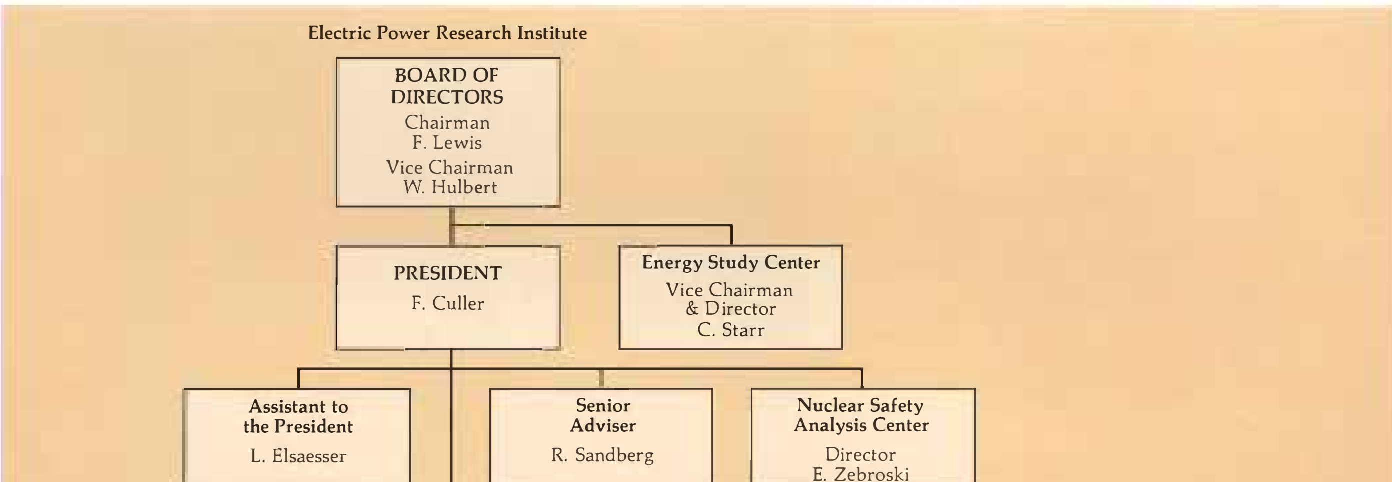
Glenn Barber will direct the Administrative Operations Division, reporting to Saxe. Edward McSweeney, controller, has assumed additional duties as corporate treasurer.

R. L. Rudman has been named director of the Policy Planning Division. Louis Elsaesser has become assistant to the president and will continue to serve as manager for Industry and Advisory Affairs.

Ray Schuster was named the new director of EPRI's Communications Division, while former director Robert Sandberg has become senior adviser to President Culler.

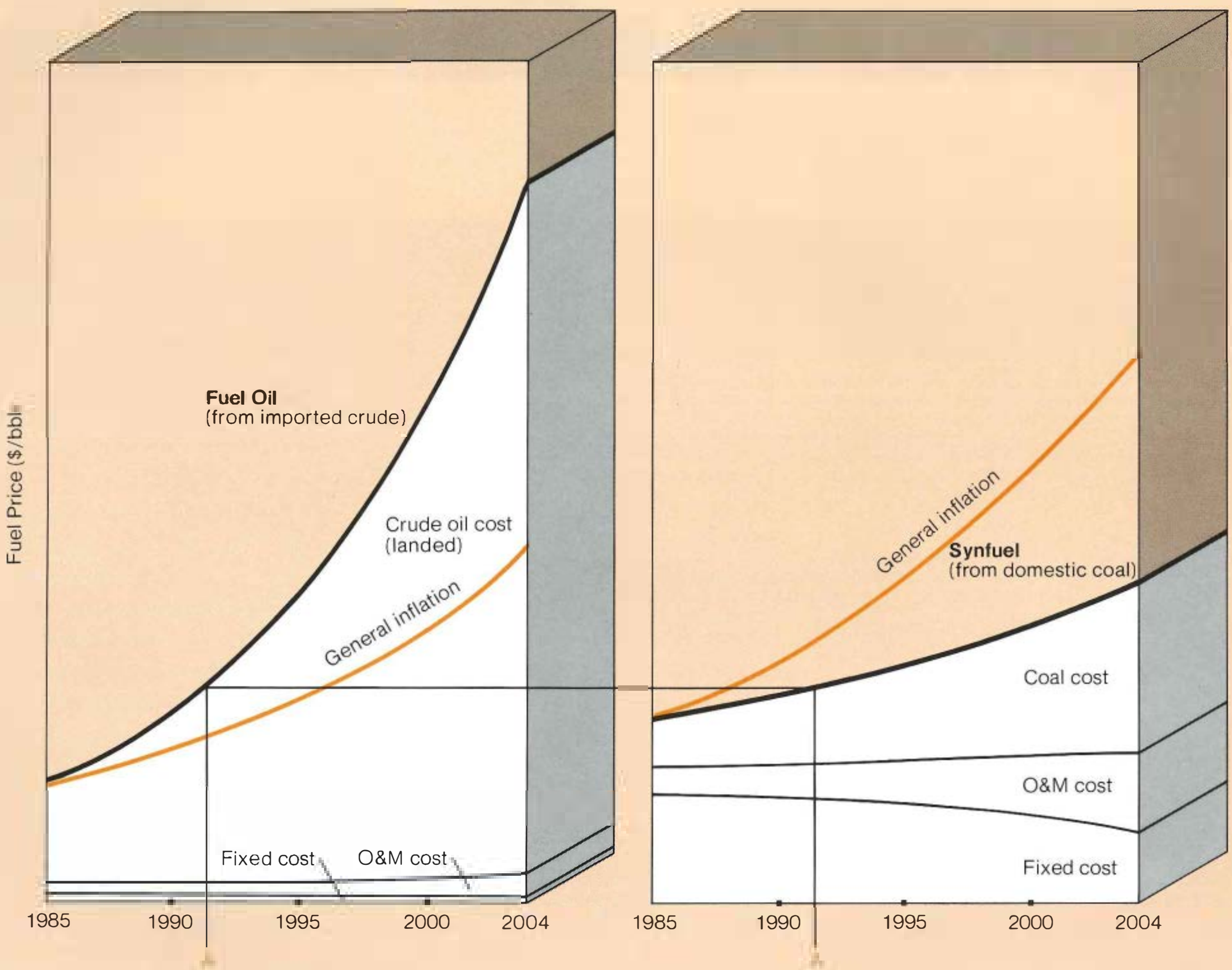


Management Positions



Synthetic Fuels Cheaper Than Oil?

Yes, says an EPRI comparison of estimated prices from mature commercial plants. But the financial incentives to build those plants will also determine when synfuels become the best buy.



Crude oil cost escalation drives the fuel oil price upward at 4% above a general inflation rate of 6% annually. For the same period (1985 and beyond), fixed charges on heavy capital investment restrain the escalation in synfuel prices. Because those fixed charges are not subject to inflation (and decrease as capital is retired), the weighted average of the three synfuel price components escalates slower than the general inflation rate. Under these circumstances, the theoretical selling price of the synfuel falls below that of fuel oil after time *A*.

Depending on two major assumptions, synthetic fossil fuels should become cheaper than oil. The assumptions are that oil prices will continue to escalate faster than the general rate of inflation between now and the end of the century and that synfuels will be developed and produced in appreciable quantity—therefore at costs reflecting mature plant efficiency and economy.

An economic analysis was prepared this past summer by EPRI's Advanced Power Systems Division because of the many questions surrounding proposals for federal energy legislation and because of the implications to electric utilities of the Fuel Use Act of 1978, which precludes new oil- and gas-fired power plants. The work took the form of a brief summary report comparing product price trends between 1985 and 2000 for natural petroleum, coal-derived liquids, methanol, shale oil, and coal-derived intermediate-Btu gas.

What made the report unique was its presentation of the various fuel prices as they could be expected to evolve under each of five different financial incentives to synfuel producers. These incentives not only would stimulate industry development but also would influence when each synfuel could become competitive with oil. According to Michael Gluckman, one of the report authors, directly comparable estimates of this kind, assembled by one methodology with uniform economic criteria, had never appeared in the open literature available to synfuel policy planners.

Four major conclusions

Capital and operating cost projections for the various technologies were collected from studies conducted by EPRI and other private organizations during the past five years. The price trends were then based on the assumption that crude oil shows a real-price increase of 2–4% per year, over and above a general inflation of 6% per year. Some of the major conclusions are these:

□ The ability of developers to raise the risk capital needed to start building a synfuel industry will limit the rate of development.

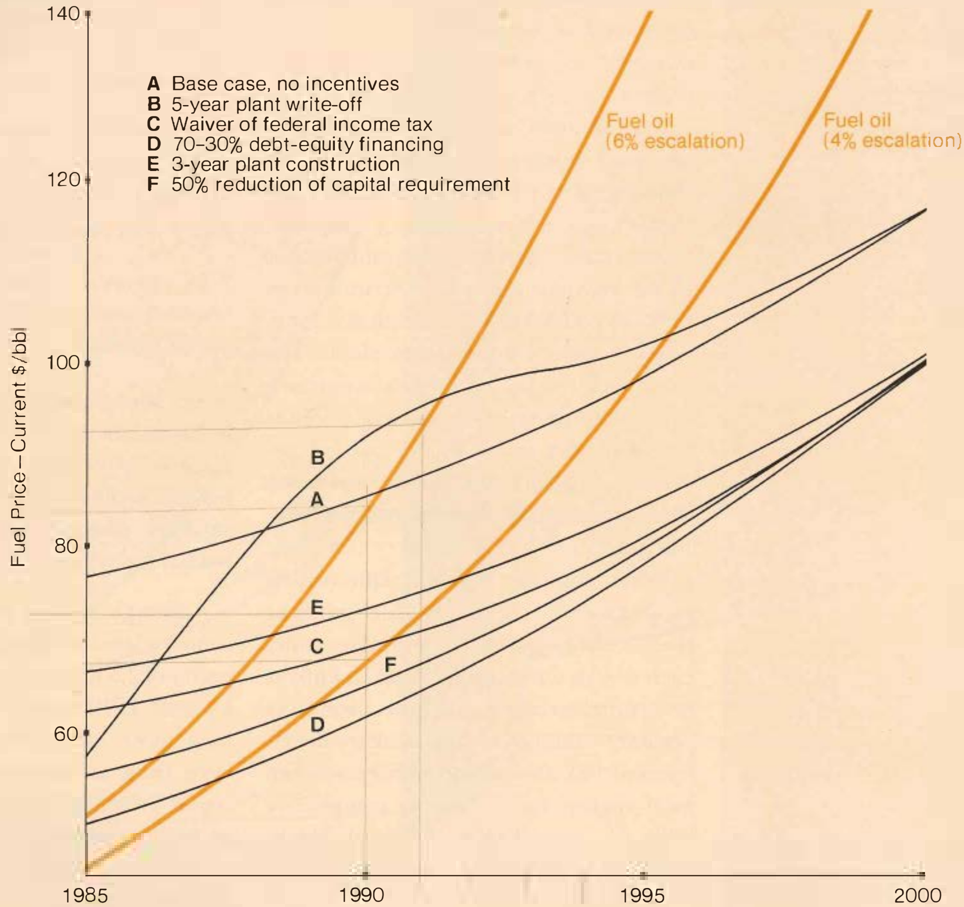
□ Shale oil and intermediate-Btu gas are the least expensive synfuels and require the least financial incentive to attain price parity with petroleum products.

□ In general, predominantly debt-financed plants will yield the lowest-priced synfuels.

□ Tax laws allowing industry to expense its capital investment during each year of plant construction will yield the second lowest synfuel price and require the smallest direct capital outlay by the federal government.

Although federal proposals last July contemplated a synfuel production capacity of 2.5 million barrels per day (mbd) by 1990, EPRI's analyses showed 1995 to be a more likely date for this volume, even from an aggressive program. The report therefore includes one example of an initial synfuels industry composed of coal-derived liquids (1.5 mbd), shale oil (0.5 mbd), and intermediate-Btu gas (0.5 mbd equivalent). This would require $40–$70 billion in subsidies, depending on specific processes, feed coals, and startup dates.

A collateral conclusion touches on the earlier need for technology pioneering or demonstration plants at the equipment scale of commercial production plants. One such program might comprise three coal-derived liquids plants, three coal gasification plants, two shale oil projects, Six alternative price trends for coal-derived liquids are compared on the basis of production from a nominal 50,000-bbl/d commercial plant, starting in 1985. Without financial incentive (A), the synfuel price starts at $77/bbl but achieves parity with oil in 1990 or 1995, depending on the escalation of oil. Five financial incentives drop the 1985 price of coal-derived liquids to a range of $50–$66/bbl; and four of those incentives yield a price advantage over imported oil in 1992 or earlier



and two so-called indirect liquefaction plants that produce fuels via an intermediate coal gasification process. These would require additional subsidies of $20–$40 billion. Several of the advanced synfuel processes are proprietary, EPRI observes, and the preferred approach of their developers is for tax incentives that would preserve proprietary positions.

Comparison, not prediction

Five financial incentives are a feature of the EPRI report, which carries a purposely restrictive title: *A Comparative Analysis of the Implications of Various Incentives for Mature Synthetic Fuels Plants.* The key qualifying words are *comparative, implications,* and *mature.*

Prices are valid only as comparative indexes because no commercial plants exist as a source of factual data. The report is internally consistent because the underlying cost estimates for all the synfuels were assembled on a uniform basis and subjected to one set of economic criteria for projecting year-by-year results.

The implications of the five financial incentives are clear in their effect on each synfuel price trend and the time to attain parity with oil. By developing these implications separately for each generic synfuel technology, it was hoped that a few incentives would become evident as having wide applicability.

Analysis based on mature plant production is important because it gets away from the separate and conjectural issues of technology development and demonstration costs. This assumption emphasizes the limited and specific purpose of the report: to permit comparisons of synfuels and incentives, not to make predictions. At the same time, it permits those comparisons to be made on the basis that is ultimately of widest interest: routine production, availability, and price from plants of nominal 50,000-bpd capacity.

Escalation of price components

Among EPRI's economic assumptions, three are especially important to a conceptual understanding of the fuel price computations and their trends through time, both with and without incentives.

First, general economic inflation was set at 6% per year. This rate governs escalation of the operation and maintenance (O&M) cost for any synfuel plant throughout its life, as well as the escalation of plant capital between now and when that plant is built.

Second, the price of coal (Illinois No. 6 in all cases) was escalated at 7.1% per year from a 1978 base figure of $1.14 per million Btu.

Third, the price of petroleum was escalated at two rates, 8.12% and 10.24% per year, from a 1979 base of $26.75 per barrel (refined). Two values were used because of the total lack of certainty. Both include 6% annual economic inflation, plus alternatives of 2% and 4% annual increase in real price caused by market scarcity.

Petroleum price does not include any significant fixed-cost increment from new capital investment. The facilities are largely in place. This price is driven entirely by inflation and market factors, and EPRI's curves for oil price thereby bring that fuel to $100 or $130 per barrel in 1995, measured in dollars of that year. (If this seems startling, one of the private company reports reviewed by EPRI noted that oil escalation from 1973 to 1979 was at the rate of 35% per year.)

Synfuel price escalation, on the other hand, is severely limited by the effect of fixed costs that result from a heavy increment of new plant investment. Those costs do not inflate with time. For the purposes of EPRI's comparisons, plant investment was assumed to be complete by 1985, after a five-year construction period. Return on investment is thereafter a uniform and constant 15% on a sunk, nonescalating capital cost.

Because only O&M (at 6% per year) and coal (at 7.1% per year) escalate after 1985, the net escalation of synfuel price—a weighted average of fixed costs, O&M, and coal—is about 4%, well below the general economic inflation rate of 6%. Thus, although synfuel prices initially are higher than those of oil, their upward trend is slower. When the curves of oil and synfuel cross, their prices are equal, and synfuels are thereafter on an equal market footing with oil. The time to this point depends on the financial incentive applied.

Five financial incentives

The obvious question from any oil- or gas-burning utility is, When will synfuel price parity really occur? The answer is, When the technologies—preferably more than one—are deemed ready for full-scale deployment and the overlapping construction periods (perhaps five years each) can begin for several large plants. By traditional measures of process development, the fourth or fifth plant can be considered mature. Depending on the individual technology and the financial incentives to its developer, a synfuel might be cheaper than oil on the first day of plant operation, or not for 10 years.

For each synfuel, a basic curve of prices (Case A) was plotted, assuming 100% equity financing without incentives. In addition, curves were plotted under each of these assumptions:

- Case B: Five-year write-off of capital investment, rather than the 13 years normally used as the depreciable plant life for tax purposes
- Case C: Waiver of federal income taxes on synfuel revenues during the 20-year operating life of the plant
- Case D: Plant financing by a combination of 30% equity capital (at 15% after-tax return on investment) and 70% debt (at 9% interest)
- Case E: Accelerated plant construction, three years instead of five (with production beginning in 1983)
- Case F: Plant capital requirement reduced by half (This is equivalent to a direct 50% subsidy or to annual write-off of construction costs as incurred.)

The effects of these financial incentives are generally similar for all the generic synfuels analyzed. The time to parity with oil varies. Shale oil and intermediate-Btu gas have lower capital costs than do coal-derived liquids and methanol. For this reason they are cheaper at the outset; they become directly competitive with oil in as few as three years; and they benefit less from any of the selected financial incentives.

Which financial incentive is best is a subjective judgment. Different companies and industries have different views. Trade and industry articles (notably those of the *Energy Daily* on August 8 and August 20, 1979) reported the range of opinions voiced by synfuel developers and energy companies as they watched events in Washington.

For example, fast tax write-off, particularly on a year-by-year basis, is highly preferred by very large companies because they have revenues large enough to take advantage of such deductions and thus minimize the period of risk. The largest companies also have sufficient equity, so they would not be likely to take advantage of high debt-equity ratios, preferring to make their own investments and profit on the return from them.

Smaller companies, essential in the encouragement of a spectrum of synfuels and of industrial competition, favor less-accelerated tax write-offs, debt-equity financing, and the waiver of federal income tax, even though these options inevitably delay synfuel price parity with oil. What becomes apparent, and one reason for EPRI's comparison of the various incentives and their effects, is that two or three incentives will be needed.

Federal loan guarantees are almost a separate subject. Debt financing will surely be needed in establishing an entirely new and capital-intensive industry. A ready capital market exists, in the opinion of EPRI's report authors, but the risk is such that no feasible increase in interest rate would alone attract the requisite billions of dollars. Loan guarantees

WHY UTILITIES NEED SYNFUELS

One way or another, it is the unknown costs of synthetic fuels that confuse or delay national decisions to bring them into commercial reality. There is the unknown cost of the technology developments themselves, of any single commercial-scale plant, and of all the plants that would inevitably be needed for a mature and competitive industry. Above all, there is the unknown unit cost of the fuels produced, whether for automobiles, home heating, utility boilers, or manufacturing processes.

The move away from oil and gas

Equally important, however, is the cost of doing without synthetic fuels—continuing to burn oil and natural gas. The Fuel Use Act of 1978 precludes that for new plants, and it precludes that for existing plants after 1990. Even more recently the president's announced policy objectives underscored the point by calling for a 50% cut (from 1977 levels) in utility oil use by 1990. As utilities plan their use of any mix of generating fuels and plant types during the next 10 years, it is reasonable for them to anticipate even more restrictions on oil and natural gas as national priorities harden in favor of what are seen as higher uses.

With pressure from other commercial sectors of the economy and with encouragement from the federal government, oil refiners are already shifting their operations toward a different product mix. On an immediate, season-to-season time scale, heating-oil stocks are being emphasized at the expense of transportation fuels. On the short-term scale of a few years, refineries are being modified and hydrogen-generating facilities added to produce a greater proportion of transportation fuels from each barrel of crude at the expense of heavier fuel oil products.

Preserving utility capacity investment

Faced with these realities and reasonable projections, utilities must weigh the prospective cost of synthetic liquid and gaseous fuels against the cost of totally scrapping and replacing up to 30% of today's generating capacity, the part that is fueled by oil and natural gas, long before its cost is recovered in a normal 30–40-year economic life of electricity production.

Absurd? Yes. Not only would the lost investment be intolerable to utilities and to the economy, but what would replace the lost capacity? Neither coal-fired nor nuclear plants, though functionally appropriate, could fill the gap. Lead times are too long; public acceptance is an issue; and environmental control and safety measures are rapidly escalating the capital costs of both alternatives. It is already nip and tuck whether utilities can provide foreseeably needed new generating capacity, much less replace so much of what is now in place.

Even if synthetic liquid and gaseous fuels are the only game in town for utilities, how will the technology choices be made, and what workable means can be devised to meet their costs? In their own interest, but necessarily also in concert with other industrial sectors of the national economy, utilities urgently need to find answers to these questions.

would probably be favored by the smaller companies and by regulated industry, such as the electric utilities.

$100 million in EPRI synfuel research

EPRI's concern with synfuel costs and industry development goes well beyond the single comparative analysis reviewed here. The Institute has underwritten extensive R&D since 1973. Its technology assessments and sponsored research have covered a wide range of synfuels (mostly those derived from coal), gradually narrowing the number of candidates of utility interest. EPRI funding has supplemented that of the federal government in supporting several advanced process developments. Especially, it has paid for specific research to adapt those processes for production of utility fuels and to evaluate prototype fuels in utility boilers.

This work, largely carried on by EPRI's Advanced Power Systems Division, has cost about $100 million so far, much of it in connection with what have become some of the best-known synfuel processes in the United States today: SRC-I, SRC-II, H-Coal, Exxon Donor Solvent, Texaco's partial oxidation, Combustion Engineering's two-stage entrained gasification, and the slagging gasifier jointly under development by British Gas Corp. and Lurgi. The Advanced Power Systems research programs for the next five years are estimated at $225 million.

During the summer of 1979, both Dwain Spencer, division director, and Richard Balzhiser, vice president for research and development, drew on EPRI's research experience for their testimony in congressional hearings on pending energy bills that could influence the course of synfuels (*EPRI Journal,* September 1979, p. 30).

Two objectives for early development

Since then, and since preparing the comparative analysis of synfuel financial incentives, EPRI has also illuminated the essential distinction between the synfuel capacity and the synfuel capability that might best be sought by the United States in the coming 10–20 years. In a draft paper on synfuel issues in August of this year, Balzhiser emphasized two objectives in support of the federal administration's goal of reducing oil imports.

□ Build relatively modest early synfuel production capacity (perhaps 1 mbd), for example, by licensing the Sasol technology now in commercial use in South Africa for production of gasoline and fuel oil. Coal-based methanol plants could also be built immediately, and several Sasol and methanol plants could be online by 1990, lessening the impact at that time of planned cuts in oil imports.

□ Build 10–15 plants to demonstrate the capability of several advanced synfuel technologies. These could be proved by the late 1980s, and at 5000–15,000 bpd capacity each, they would provide as much as 150,000 bpd. More important, they would be a ready basis for further capacity expansion when needed and would have the capability to produce the full range of liquid and gaseous fuels needed by the U.S. economy.

The paper also underscored the need for tax and price incentives to stimulate industry participation with the least distortion of fuel, capital, and other economic markets. Finally, the paper endorsed the concept of fast-track plant licensing and permits, which is contained in the proposal for the federal Energy Mobilization Board, and suggested its extension to state level.

In EPRI's view, its work and its insights on behalf of electric utilities lead to a general conclusion that is shared by national energy policy planners: the need for synfuel technology development. The open question at this writing is the most workable means for meeting its cost. As Balzhiser's August paper notes, "The initial cost will be high, but . . . in the decade of the 1990s, synthetics will likely be essential to ensure adequate fluid fuel supply." ■

ECONOMIC CRITERIA FOR COMPARATIVE ANALYSIS OF SYNFUEL PRICE TRENDS
(financing by nonregulated industry)

Year of first investment	1980
Year of commercial operation	1985
Construction period	5 yr
System life	20 yr
Depreciable life for tax purposes	13 yr
Depreciation for tax purposes	Sum-of-years' digits
Capital and operating cost escalation rates	6.0%/yr
Coal escalation rate	7.1%/yr
Coal cost in 1978 $ (Illinois No. 6)	$1 14/$10^6$ Btu
Federal income tax rate	48%
State income tax rate	4%
Investment tax credit	10%
Property taxes (% of initial depreciable capital)	2%/yr
Insurance (% of initial depreciable capital)	1%/yr
Return on equity after taxes	15%
Interest on debt	9%
Plant design capacity (bbl fuel oil equivalent per day)	46,000
Annual on-stream operating factor	90%

Tuning Out Transformer Noise

A tuned noise-reduction shell developed by EPRI may be an effective and relatively inexpensive solution to humming transformers.

Utility engineers may find the hum of a transformer reassuring—a signal that power is traveling unimpeded to distribution points. But, understandably, many people who live near transformers prefer silence. Because populations around power plants, substations, and distribution lines are growing, noise complaints are an increasing problem, and the number of noise-control ordinances is mounting. So the electric utility industry needs an effective, inexpensive means of noise control.

Utilities rely on a number of technologies to blanket transformer noise. One popular method is a free-standing sound barrier, such as a $\frac{1}{2}$-inch-thick steel enclosure lined with 2-inch-thick fiberglass. Sometimes a utility surrounds a transformer with a brick or a concrete wall. Or the flux density of the transformer's core is reduced, thereby reducing the magnetostriction that causes the hum. However, none of these solutions is inexpensive, particularly when applied to larger transformers.

A noise-reduction shell developed by

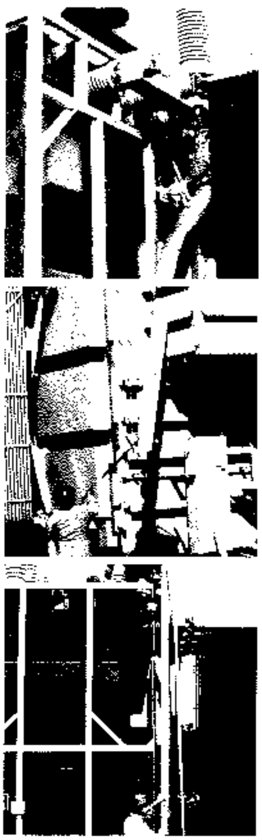
EPRI and Allis-Chalmers Corp. may be the answer. The shell, an assembly of lightweight tuned panels that fits snugly over the offending transformer, can cut noise by up to 15 dBa and undercut the price of other noise-control alternatives.

An English researcher first theorized that sound barrier panels integrally mounted on a transformer exterior could be tuned to reduce the sound level emitted from the transformer tank at discrete frequencies. The tuning could be accomplished by adjusting such variables as the distance between transformer and panel, panel stiffness, density, damping, thickness, and support. Aware of the need for improved noise control, EPRI decided to try to verify and apply the theory.

Basic transformer sound characteristics had to be identified. Six 45-MVA transformers, owned and operated by Wisconsin Electric Power Co., were chosen for field-testing. Sound spectrums for these transformers were found to be generally consistent; the most significant sound frequencies identified were in the lower ranges, between 120 and 600 Hz.

Next, individual transformer noise sources had to be painstakingly isolated and ranked according to magnitude. Two different approaches were used. One was a technique in which all sources but the one being measured were surrounded by fiberglass-insulated plywood enclosures, and direct noise readings were made. Because it is difficult to isolate any single transformer element, a new vibration-conversion method was also tried. Vibrations on particular transformer elements were measured, then those measurements were converted into equivalent noise levels. There appeared to be generally good correlation between actual, measured noise levels and the noise levels derived from the vibration measurements.

This source-ranking revealed that the radiators used to cool insulating oil are a significant source of noise. So are the reinforcing ribs on transformer walls. On pier-mounted transformers, the transformer bottom was also an important noise source.



The noise-reduction shell, an assembly of lightweight, tuned panels that fits snugly over a transformer, can cut noise by up to 15 dBa.

Meanwhile, the noise theory was coded for computer use and a special fixture constructed for laboratory tests on a variety of materials and panel configurations. Test results compared favorably with the theory, and both fixture and computer were used to assist design efforts. Steel and ABS plastic were identified as choice panel materials.

Eventually, an experimental 11-gage-steel noise shell was designed, built, and tested on one of the transformers. Noise reductions of 8 dBa were achieved. Although lower than the goal of 15 dBa, this demonstrated that the theory was valid. Other analyses indicated that the noise shell was the most economically attractive solution where multidirectional sound reduction was required.

In a follow-up project, damping of the enclosure material was found to be critical for optimal noise reduction. The experimental shell's record of 8 dBa hit the 15-dBa target with the addition of damping material. And on a complete shell installed on a 60-MVA transformer at Consumers Power Co. in Jackson, Michigan, the 8.5-dBa noise reduction achieved by installation of plastic panels was increased to 11.6 dBa with the addition of acoustic foam. When three plastic panels were replaced with damped steel panels, a 16.5-dBa reduction was attained. Subsequent project efforts focused on the commercial design and demonstration of the shell for retrofit applications.

Cost savings possible with the noise shell vary with transformer configuration and size, notes Project Manager Edward Norton. In some cases, the noise shell might not be the most cost-effective choice. But projections indicate the shell will cost about 40–50% less than standard noise control.

Of course, the final test of success is the marketplace, and even there the noise shell is getting positive feedback. Bonneville Power Administration plans to use the shell to help muffle a 1008-MVA transformer bank to satisfy Oregon noise regulations. And Allis-Chalmers reports nibbles of interest from other utilities.

Does the United States Waste Energy?

For several years popular belief has held that the United States uses more energy per dollar of output than do most developed countries. This belief lends itself to the easy interpretation that the United States is inefficient in its energy use and that conservation is a simple matter.

During a news conference in October 1977, President Carter stated, "We are simply wasting too much energy. For the same standard of living, we use twice as much energy as is used in Japan, West Germany, Sweden, and other countries of that kind. So, we have got to cut down on our waste through conservation measures, voluntary action, and a realization of the seriousness of this question."

Is such a statement (and its implications about the United States) correct, incorrect, or just conventional wisdom? A few facts may illuminate the complexity of the matter.

The United States, taken as a whole, does use more energy per capita than these other countries, but when U.S. energy consumption is broken down into regional figures, a very different picture appears.

Take the New England states, for instance. Although their combined population is similar to Sweden's, they achieve a greater economic output for each unit of energy they consume than does Sweden. Likewise, the northeastern sector of the United States produces approximately the same amount of goods and services for every unit of energy consumed as does West Germany.

As a reflection of the total economy of the United States, on which energy has a significant influence, the average U.S. worker can purchase more goods and services with his or her annual income than the average wage earner in Sweden or in West Germany. In light of these facts, words like *waste* and *inefficient* seem inappropriate to describe the United States' use of energy.

The specific amount of energy produced or consumed is really not the issue. The question as to whether energy is being wasted is more one of quality than of quantity. We should be asking how well energy is used, not how much; that is, do Americans use energy efficiently?

A confusion apparently exists between energy efficiency and economic efficiency. The latter seeks the most effective use of all resources, of which energy is only one component. Economic efficiency results in the end use being achieved with a minimum integrated waste of all resources, balanced in some value system. Selecting only energy input as a matter of special concern may not be the most desirable approach for the economy as a whole. For example, if the labor and capital costs of constructing a heat-recovery boiler in a power plant exceed the potential value of process heat recovered, then that exhaust heat can hardly be said to be wasted. The same kind of overall economic considerations are appropriate in getting a balanced view of whether a power plant, an industry, a state, or a nation does or does not waste energy.

Data interpretation

Many of those who believe the United States uses energy inefficiently base their arguments on studies that compare energy consumption in the United States with energy consumption in other countries that also achieve high standards of living, such as Sweden, West Germany, and Japan. For instance, results of one study show that the average Swede uses less than two-thirds of the energy used

Stepping behind international statistics, researchers find wide differences in the people of modern industrial societies—differences that characterize people's living patterns and determine the way they allocate resources, including energy.

by the average American. Other research findings report that West Germans and Japanese consume energy for transportation at about one-fourth the level that Americans do.

These data clearly demonstrate that the United States does use more energy per person than other similarly developed countries. But it is important to go further than these data and to interpret them in the light of other equally valid aspects of economic reality, which can be termed the economic infrastructure. This infrastructure embraces a wide range of activities and tendencies, each of which is characterized by different amounts of energy used, or energy intensities. Some factors in the infrastructure are listed by Joy Dunkerley, senior research associate of Resources for the Future, Inc., and editor of *International Comparisons of Energy Consumption*, the proceedings of an EPRI–RFF workshop on the subject (RFF R-10). She finds that these factors include "the size of industrial sector, importance of energy-intensive industries in the industrial sector, differences in product mix, vintage of energy-using capital stocks, climate, population density, propensity to travel, policies affecting use of energy and other input factors, and lifestyle attributes, such as the premium people place on time or on personal comfort."

Because national infrastructures vary, comparative international statistics alone can be misleading. Sweden and the United States, for example, differ in climate, culture, geographic distribution of population, and diversity of activities. The same is true when comparing the United States with West Germany or Japan. Dunkerley observes, "Differences in structure among countries go to the heart of the question of the usefulness of international comparison. If such differences of structure cannot be systematically sorted out, then it is difficult to make valid international comparisons."

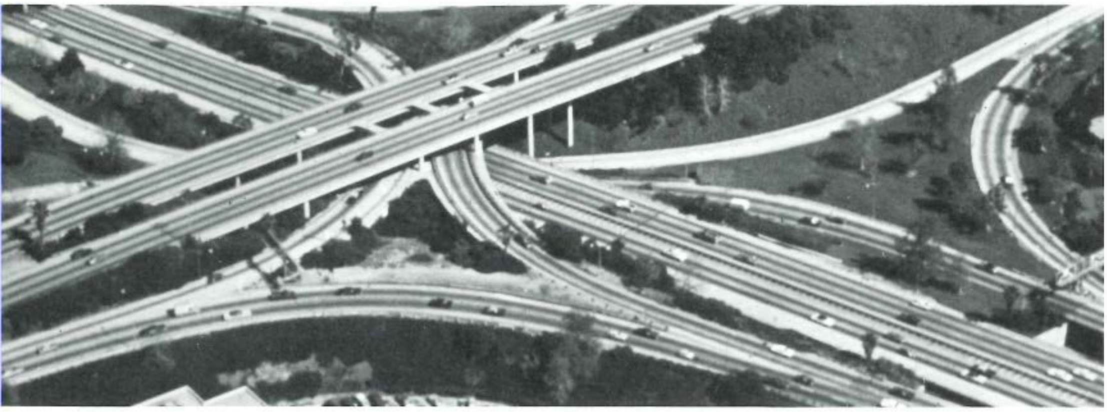
To find the key to the reasons for energy use patterns in a country means examining the influence both of people's incomes and of market price mechanisms. It also means stepping behind the statistics to the customs and the social preferences of the people of a country. The point is that statistics, such as the ratio of energy use to economic output (gross national product), do not necessarily reveal the reasons for what is going on in a particular society.

Incomes and purchasing power

Although we do know what is going on in the United States, that is, more energy is used per person than in other industrialized nations, especially for transportation, researchers propose a number of reasons for these statistics. Opinions differ widely, too, over whether the United States could easily eliminate this apparent margin of energy, or at least reduce it considerably.

Work done for the United Nations by Irving B. Kravis, head of the International Comparisons Unit of the University of Pennsylvania, indicates that it is income, and thus purchasing power, that influences consumption levels, whether as energy use, car purchase, or telephone service. But the results of Kravis's international research also document the fact that living standards of nations (measured by comparing the value of goods and services purchased, in dollar terms) are better gauged when corrected for misleading exchange rates, which do not accurately reflect living costs. Incorporating so-called purchasing power parities, Kravis's results for 1978 confirm that the United States has the highest domestic purchasing power in the world (although

Energy use in transportation is closely related to a country's geographic features and urban development. One nation may be compact enough to benefit from mass transit systems; another must build vast freeway networks to permit efficient travel between sprawling suburbs.



several other countries show higher per capita income when the figures are based on exchange rates). This high level of U.S. purchasing power is thought by some observers to be the reason for the high levels of energy consumption in this country.

Chris Whipple, technical manager, EPRI Energy Study Center, explains, "You recall back in the 1950s and early 1960s, Americans thought travel in Europe was a great buy; things were cheap when compared with prices at home. That's because the purchasing parity differed from the exchange rate in such a way that incomes of Europeans appeared much lower than those in the United States. Actually, because their prices were also lower, their real incomes weren't that much lower. And now it's reversed. Americans go to Europe and complain about how expensive it is because the purchasing power parity has shifted the other way. And the reason there can be such a parity is that the amount of trade compared with the total amount of goods is small. In terms of the actual goods and services that can be purchased with average incomes, the U.S. still ranks highest."

The price factor

Although high levels of consumption seem an obvious companion of high income levels, price, too, plays a powerful part in the market mechanism. For a true picture of whether the United States is energy-efficient it is essential to examine its market processes.

Giving the example of natural gas and oil prices, C. F. Anderson, an economist in EPRI's Special Studies Department, says, "By allowing the market mechanism to determine price, producers of goods and services and their consumers can be directed to a new employment of scarce energy resources. Price best allocates resources, and it's only when this mechanism is constrained that we end up with problems."

Up to now, Americans have acted on the belief that it is worth adopting more-efficient methods of energy use only if they really save money in the long run. The price of capital expenditure has to be justified by a future payoff. Whipple takes up the point, "If fuel prices are very low and you use a lot of energy to heat your house because it isn't insulated, it's not waste—not if it's cheaper to buy energy than it is to buy insulation. It's a sensible trade-off. If fuel prices are quite high, however, as they have been for the past several years, and you still use a lot of fuel, that's waste, because it's cheaper to buy insulation."

In a July 1979 paper (No. E-79-02), "Dimensions of Energy Demand," William W. Hogan, director of the Energy and Environmental Policy Center, Harvard University, states, "This is the theory of the market system: Where left alone, the market system for energy has worked reasonably well in the past, and it can be made to work well again in the future. The higher prices of energy are neither a crisis nor the essence of the energy problem. If we can manage the adjustment to a new era of energy scarcity, the higher prices may be the solution to the energy problem. A sensible energy-pricing policy can help us manage the many adjustments that must be made by providing the incentives to make the substitutions that are possible."

Thus Americans, even with their comparatively high average individual incomes, are likely to respond to changes in energy prices, just as they would if some other commodity became scarce and therefore expensive. But other

powerful factors influence U.S. energy use, as mentioned before. These are national geographic characteristics, such as climate and vast travel distances, and social specifics, such as culture and population densities. In these, the United States differs from the countries with which it has been compared: Sweden, West Germany, and Japan. It can be helpful in evaluating energy use to look at the way people of those countries conduct their day-to-day lives.

Swedish indicators

Swedes use less than two-thirds as much energy per person as Americans do, according to an article by Lee Schipper and Allan J. Lichtenberg of the University of California at Berkeley (*Science*, December 3, 1976). That is, the ratio of energy consumption to economic output is much lower for Sweden than for the United States. But ratios indicate less vividly what is really going on in a country than does a look at the basic consumption and production patterns of its people, as Schipper and Lichtenberg agree.

Comparing modes of transportation in the United States and Sweden demonstrates major differences between the two countries. According to Schipper and Lichtenberg, the Swedes rely to a large extent on mass transportation. "In Stockholm, Göteberg, and Malmö, where more than 25% of Sweden's population resides, mass transit, motor bikes, and pedal bikes account for 75% of all commuting." For the entire country, the figure is approximately 45%.

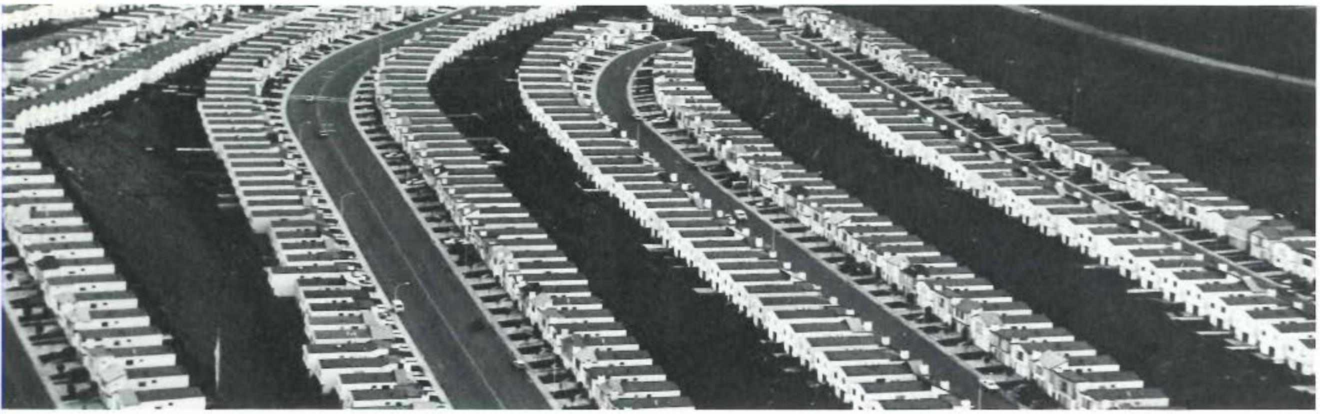
Those Swedes who prefer to travel by car are relatively frugal in their consumption of gasoline. A contributor to this efficiency in Swedish vehicles is the lower average weight of their cars compared with the average car weight in the United States, the absence of air conditioning in vehicles, and a limited use of automatic transmission.

The American middle-class norm of two cars per family is unknown in Sweden but so is the low population density of U.S. suburbia and the consequent necessity for daily motorized travel. Teenagers behind the wheel in Sweden are not a common sight; they must wait until their eighteenth birthday before they are eligible to hold a driver's license. And learning to drive is not part of the high school curriculum as it is in many U.S. school districts. Only private driving academies teach new drivers—at a cost equivalent to several hundred dollars. Because of the expense, many young Swedes have to forgo driver training until they have been working long enough to afford it.

A further stimulus to Sweden's low energy consumption for transportation is the heavy tax on motor fuels, which Sweden has to import. This is reflected in gasoline prices that are appreciably higher than in the United States—about $2.25 per gallon.

The Swedish residential-commercial sector, on the other hand, runs on relatively inexpensive electricity, produced by abundant hydropower in the north of the country. Heating oil, too, is relatively cheap, although the winter season is so long that Swedes are conservative in its use. Being conservative with heating oil, however, is possible because of prior expenditure on construction of buildings that are thermally efficient. The Swedes are zealous insulators; they double-glaze windows and construct large units of apartments and offices to reduce the number of exterior walls, thereby effectively cutting the heat loss from buildings during freezing weather.

National energy prices and regulations lead to considerable differences in the ways people of developed countries construct, insulate, and heat their homes and workplaces.



District heating is also part of the Swedish policy of efficient energy use; central stations either produce heat alone or cogenerate heat and electricity.

The industrial sector in Sweden gains in energy efficiency from its modern capital equipment, both in the steel and in the pulp and paper industries. The high cost of fuel, most of which has to be imported, is clearly a stimulus to such energy efficiency. Fuel costs also force a selection of industrial activities whose products have high economic value per unit of energy consumed.

The West German case

West Germany's reasons for lower energy consumption are similar to Sweden's. Overall figures given in a 1975 SRI study, "Comparison of Energy Consumption Between West Germany and the United States" (GPO: 1975-633-415/100 3-1), show the West German per capita energy use as percentages of that in the U.S.: industry, 60.8%, residential-commercial, 52.1%; transportation 25.7%. For all sectors, the percentage is 48.8%. (However, a comparison with the northeastern United States shows little difference from West Germany.) Part of the reason for the low percentages in the industrial sector has to do with newer capital goods in Europe and efficacious selection of industries. Much of the capital was replaced after WWII, whereas the United States employs a lot of prewar capital. The moderate residential-commercial and transportation figures have to do with both lifestyle and the demographic distribution of population.

In West Germany, 29% of electricity is produced by industrial cogeneration. Some industries use such energy savers as heat recovery boilers.

In residences, only 45% of the floor space is heated, according to the SRI study; the West Germans insulate with double glazing and closed entrance hallways. The per capita use of energy for domestic hot water is about one-third of that in the United States. Most West German families heat their water with small point-of-use and heat-on-demand systems.

Why the low energy consumption in the transportation sector? Once again, less passenger travel and freight transport and also better gasoline mileage per car in West Germany.

Life in Japan

The Japanese apparently conserve energy in transportation and homes in much the same way as the Swedes and the West Germans. A typical Japanese rides a bicycle to the mass transit terminal every morning and then walks from the destination terminal to the office.

The family car (and there is commonly just one per household) is rarely used for commuting, or even for vacations; its more usual trip is transporting the family to a park or the coast for a weekend outing. When it is vacation time, people take the train to their recreation spot; they can travel almost anywhere in Japan on the railroad network.

However, labor strikes sometimes paralyze the mainly nationalized railroad systems, and for this reason much freight is delivered by truck. The Japanese government is building more express highways and plans construction of more interisland bridges and tunnels. But even if road transport, and therefore fuel consumption, increases, the length of any journey in Japan is limited to a fraction of the mileage necessary in the United States. Not only is Japan's land area slightly smaller than Montana, but 70%



of it is mountainous and sparsely inhabited; most people live in the remaining 30% of lower-lying land. In Japan the population density is 793 persons per square mile (in the United States the figure is 59 per square mile). People are clustered in a few main areas, and business and family visits do not require the gasoline they do in the United States.

For the Japanese, routine domestic air travel consists of relatively short flights between the islands, representing quite a difference in jet fuel consumption from the routine East Coast–West Coast flights made by Americans.

Because homes in Japan are rather small, they are relatively inexpensive to heat. Further, the Japanese have less reason to use a great deal of energy in home heating; winters rarely bring subzero temperatures in the low-lying inhabited areas. In summer, air conditioning is not as necessary as in the United States; Japanese houses are built with shutters and overhanging eaves, the same measures used in West Germany and other European countries, where electric cooling is expensive compared with the cost of insulation.

The Japanese cook their meals and heat their communal, hot-water-conserving tubs with gas, but warm their rooms with small kerosene heaters. The fuel pattern may change this winter, however, because the Ministry of International Trade and Industry lifted price controls on kerosene in June this year. Consequently, the price of kerosene has jumped 33%. The Japanese may choose to switch to gas heating (electricity is used comparatively little for heating in the residential sector).

Because Japan is a country with few natural resources, it does not have such highly energy-intensive industries as mining or basic ore processing. And because Japan imports its fuels and raw materials, it has to compensate for high import costs by using energy as efficiently as possible with modern equipment and up-to-date technology, much in the same way as West Germany and Sweden.

Regional differences

Can income, price, and specific national factors account for most of the differences between the United States and other developed countries? Could the United States re-form its national economy, its industrial infrastructure, and its social patterns to duplicate the kind of energy-economic organisms with which it is compared?

One way to approach these questions is to look at regional differences within the United States. Variations can be expected for two reasons. First, differences in incomes and energy prices establish different economic balances in each region. Second, differences in energy prices, even if quite small, can be important in influencing regional industry mix. As prices change, individuals and industries adapt, although industries with massive investments cannot just pack up and move. For these reasons, states and countries with industries that developed during times of low-cost energy are likely to retain their energy-intensive patterns for a long time.

Chauncey Starr, vice chairman of EPRI, elaborates on these factors in his 1977 study paper "Energy Use: An Interregional Analysis with Implications for International Comparisons." In the study, researchers compared states in terms of their ratios of energy use to gross state product (GSP). As Starr observes, "Those states such as Texas and

Louisiana that are noted for a large proportion of energy-intensive industries (e.g., petroleum refining and petrochemicals) and Indiana, Ohio, and Pennsylvania, where steel manufacturing is prominent, all have much lower GSP/E (gross state product to energy) ratios than those states that provide services, such as New York, which specializes in banking, insurance, and real estate.

"Further, in the generation of some GDP (gross domestic product), energy is only one factor of production. Capital, labor, and materials are also factor inputs. And societies combine these factors in different ways to produce outputs. Just what combinations evolve depends on several factors, one of which is prices. If one society shows a high GDP/E ratio relative to another, this does not mean that some given society is more efficient in its energy use. . . . Under competitive conditions, energy is being employed up to the point where its marginal product just equals its alternative cost. If this is the case, then Sweden, West Germany, and the United States probably have equal economic efficiency in their use of energy."

Starr concludes by saying that the problem of comparing countries and their respective energy uses is a complex one, and simple GDP/E ratio comparisons can lead to the wrong conclusions. Certainly such ratios do not measure efficiency.

William A. Vogely, head of the Department of Mineral Economics at the University of Pennsylvania, reaches the same conclusions as Starr. In his article "The United States: Energy Glutton or Gourmet?" (*Earth and Mineral Sciences*, January 1979) he states, "Per capita energy consumption by each of the 50 states shows a variation much greater than that demonstrated between the United States as a whole and other countries. Using 1973 data, for example, the energy consumption in Florida was 173 million Btu per person, the lowest of all the 50 states. The highest state for the same year was Wyoming, with a consumption of 637 million Btu per person, a difference of over three and a half times. Why does this great disparity exist within the United States? If we can understand that question, we can then begin to understand whether or not the United States is wasteful and gluttonous in its use of energy."

After listing a number of determinants of energy demand, Vogely states, "I would add the price of energy as being a very important determinant of energy demand within a state." In fact, Vogely concludes his article by saying that the data he developed "do indicate that within the United States energy use appears to be an efficient response to energy prices. There is no evidence that certain areas of the country use energy in a wasteful fashion in those aspects of life which relate to everyday living."

The "efficient response" referred to by Vogely is explained thus: "Economists argue that industry will locate, unless constrained by political factors, in those areas where the total cost of production, including transportation of raw materials and transportation of the finished products to market, is the lowest. Industry which has a major cost input from energy use will tend to cluster where energy costs are lowest. Thus, the high energy consumption in those states that might be classified as energy gluttons turns out not to be due to a wasteful lifestyle or conspicuous consumption of energy, but due almost solely to the fact that energy prices in those states have attracted industry which is heavily oriented to energy use."

Future patterns

What transpires in examining the U.S. infrastructure is that incomes and prices are strong determinants of energy use; geography and demographics contribute also. In an economic sense, the United States is not wasteful. As gasoline prices rise, of course, modes of transportation are bound to change; already, many Americans are switching to cars that offer better mileage per gallon of gasoline. However, mileage traveled per capita in this vast country may take longer to respond to price; it is generally thought that Americans will not give up their mobility easily.

Clearly, one effect of increasing prices is to change the current "efficient" mix of production factors (labor, materials, energy, capital) by reducing the energy consumed. But in many cases, this will not be possible on a wide scale until existing factories, houses, and automobiles are replaced with units designed to conserve energy. This innovative phase will clearly take time and new capital formation.

In addition to comparing per capita consumption rates between industrialized countries for the United Nations, Kravis and his team of economists have collected data on per capita rates of capital formation, that is, construction of new plant and installation of new equipment. If what these analysts believe is true—that a country's future standard of living depends on its present rate of capital formation—then Americans have a less bright future than do the West Germans or the Japanese.

Kravis's findings show West Germany's per capita level of capital formation as 134% of the U.S. level and Japan's level as 118%. Up to now, in the mix of available resources, the United States has habitually depended on easily available energy and land, while going slow on capital formation. In contrast, the pattern in Europe and Japan has evolved with high costs of land and imported energy. As a result, the United States must make a greater adjustment than these other countries to the pattern of high energy prices that began in 1974.

The international comparisons—at their most detailed, but not their aggregate, level—can help our understanding the adjustment to be made, for instance, where changes might do the most good. And with the expectation of increases in the price of energy, the United States has an opportunity to learn from the experiences of other countries, focusing on those examples that apply to our particular conservation needs.

Industry Response to Three Mile Island

In congressional committees and other forums in Washington, D.C., industry representatives described a three-pronged approach to apply the lessons learned from TMI.

Chauncey Starr, EPRI vice chairman, testifying.

As official Washington waited for the release of the Kemeny Commission report this fall, committees of Congress and the Nuclear Regulatory Commission (NRC) turned their attention to the industry's efforts to learn from the Three Mile Island accident and to assure that such an event never happens again.

September 28 marked six months since TMI. In hearings around that time before the Advisory Committee on Reactor Safeguards (ACRS), the House Science and Technology Committee, and the House Interior and Insular Affairs Committee, industry representatives reviewed initiatives that constitute what EPRI vice chairman Chauncey Starr termed a nationwide, mutual self-help approach geared toward assuring the reliable and safe operation of nuclear power plants.

In testimony on September 19 before the Subcommittee on Energy Research and Production of the House Science and Technology Committee, Starr noted that these utility efforts "represent a radical step toward increasing [utility] responsibility for improving the nuclear option," as well as a "reaffirmation of [utility] commitment to nuclear power as a necessary part of our future energy mix."

Starr said, "It is evident that the Three Mile Island accident stimulated the electric utilities to reexamine the institutional performance of the nuclear industry and the respective roles of the government agencies, the manufacturers, and the utility operators." And he insisted that utilities "have recognized their lead responsibility to ensure the reliable and safe operation of all nuclear power stations."

This theme of utilities' accepting the lead responsibility for assuring nuclear safety was echoed by Byron Lee, Jr., chairman of the Atomic Industrial Forum's Policy Committee on Follow-Up to the Three Mile Island Accident in his testimony on September 21 before the Subcommittee on Energy and the Environment of the House Committee on Interior and Insular Affairs.

"While the regulatory process indeed

has a specific role in assuring reactor safety," he noted, "it is, in our opinion, subordinate in its effect on real safety to the efforts of the individual utilities and the industry that supports them. The industry efforts discussed this morning should be a sign of encouragement to you and the public that nuclear safety can and will be improved."

Key congressional leaders who conducted the hearings indicated their understanding of the significance of industry actions.

"The industry response to Three Mile Island will be a key factor in determining nuclear's role in the future," stated Congressman Morris K. Udall, chairman of the House Interior and Insular Affairs Committee.

The industrywide self-help approach referred to by Starr is a three-pronged effort, addressing the consequences of TMI on a technical design level, at the utility operations level, and on a financial risk-sharing basis. The effort has resulted in the establishment of two new institutions—the Nuclear Safety Analysis Center (NSAC) at EPRI and the Institute of Nuclear Power Operations (INPO) that will be independent of all existing organizations—as well as the formation of a plan for a mutual insurance arrangement to protect utilities against costly power replacement in the event of an extended power outage following a possible nuclear accident. These three initiatives were developed under the guidance of an industry TMI Ad Hoc Nuclear Oversight Committee chaired by Floyd Lewis, president of Middle South Utilities, Inc. The committee coordinates the activities of the Atomic Industrial Forum, the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association.

In addition to these industrywide efforts, individual utilities have taken steps to improve their own nuclear operations and safety since TMI.

"Essentially every utility with nuclear power programs has initiated an internal review for self-evaluation of its activities," noted John D. Selby, president of Consumers Power Co. at the September 19 hearing before the House Subcommittee on Energy Research and Production. "Internal changes are being made to assure that the technical and managerial structures are arranged to provide a proper balance between safety, reliability, and cost of operation. Clearly, Three Mile Island taught us something."

NSAC Furthest Along

Of the three new initiatives taken industrywide, NSAC, which was established to address TMI on a technical level, is the one furthest along. It was established at EPRI in May and currently has a staff of 35 technical experts and a 1979 budget of $3.5 million. The workforce is expected to increase to 50 in 1980 and the budget to $7.5 million. Although funded and administered separately from the rest of EPRI, NSAC reports to President Floyd Culler and receives guidance from the NSAC subcommittee of EPRI's Research Advisory Committee. NSAC's mission is to investigate and generalize the technical lessons learned from TMI, to develop strategies to minimize the possibility of a future accident, and to address generic nuclear safety issues. NSAC has published a report analyzing the events at TMI that differs from other sequence-of-events reports "in that there are extensive appendixes that analyze in detail what happened physically," explained NSAC director Edward Zebroski at the September 19 hearings. "This report makes no reliance on people's recollections. The instrument charts and the computer records were the main sources of data, together with a datalogger (something like a flight recorder), which provides a more complete record of what was happening than the operators had." Future tasks for NSAC include a What If study of TMI, which will discuss, among other things, actions that would have prevented the extensive damage sustained by the plant.

The utility representatives who testified at the hearing (from left): John Selley, president, Consumers Power Co.; A. J. Phister, general manager, Salt River Project; Edward Zebroski, director, Nuclear Safety Analysis Center; and Warren Owen, senior vice president of engineering and construction, Duke Power Co.

INPO Under Way in 1980

INPO was first announced by the industry at a June press conference in Washington, D.C. Chauncey Starr was asked by the industry to design the organization framework for INPO and did so with the help of a special advisory panel consisting of individuals experienced in national safety matters. Among the members of the advisory group were Jerome Lederer, former director of safety for NASA and former head of the Flight Safety Foundation, and Dr. Joseph J. Bulmer, former head of the Naval Nuclear Power Engineering School at the Knolls Atomic Power Laboratory.

The proposed organization concept for INPO was presented to electric utility executives during regional meetings in late summer. In September the organization was incorporated and a board of directors chosen. A president is expected to be selected by the end of the year, and the institute will begin operations in 1980.

As described by Starr and other industry representatives, INPO will operate with an estimated staff of 200 and an annual budget of $11 million. "The institute will be dedicated to ensuring a high quality of operation in nuclear power plants," noted A. J. Phister, general manager of the Salt River Project, president of the American Public Power Association and cochairman of the INPO Steering Committee, at the September 19 hearing. He explained that INPO will establish benchmarks for excellence in nuclear operation and will conduct independent evaluations to assist utilities in meeting those benchmarks. He also noted that the institute will seek to enhance operator training by determining educational and training requirements for operating personnel, accrediting training organizations, and certifying instructors. Finally, he pointed to INPO's role in providing emergency preparedness coordination for the industry.

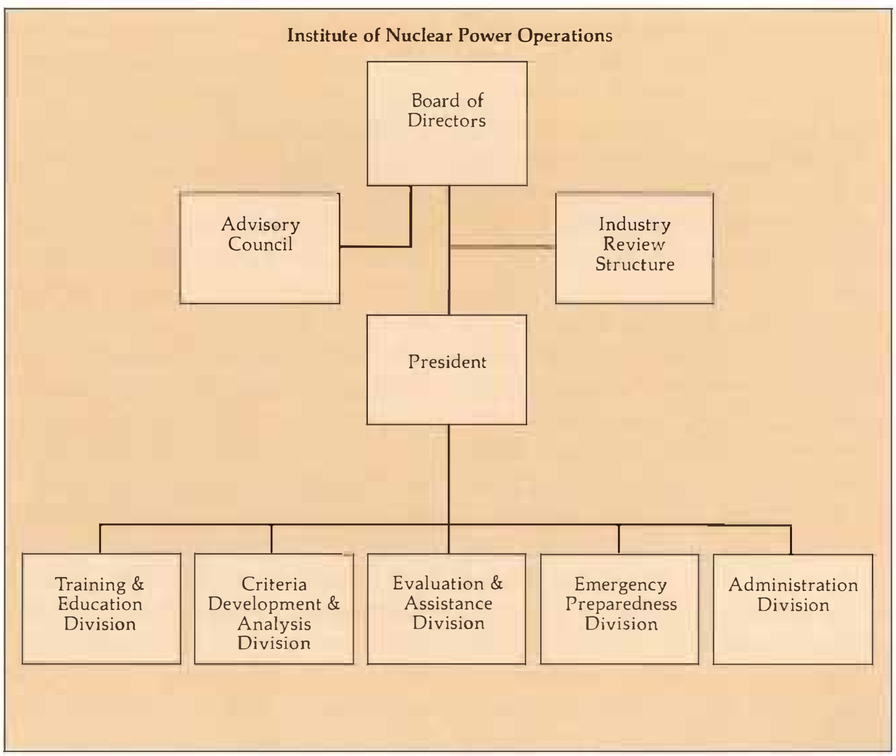
In that same hearing Starr stressed that INPO would work in cooperation with utilities in these efforts. "It will not preempt utility management responsibilities," he insisted. "Rather, as an industry-sponsored institute, it will provide utilities with the means to improve their own operations."

The complementary roles of INPO and NSAC were discussed by William Lee, chairman of Duke Power Co. and cochairman of the INPO Steering Committee, at a meeting of ACRS in early September. Noting that INPO and NSAC will figuratively "meet in the control room," he explained that NSAC will be concerned with the equipment, instrumentation, and other technical aspects of nuclear plant design and its relation to safety and reliability, while INPO will be concerned with the human engineering aspects of training, evaluation, and coordination of emergency preparedness. The two organizations will overlap in some areas, he explained, and will cooperate closely.

INPO will consist of the Board of Directors, the Advisory Council, the Industry Review Structure, the President and five functional divisions. Board members will be chosen from the industry while the Advisory Council will be composed of distinguished individuals from outside the industry, including prominent educators, scientists, engineers, industrialists, and health specialists.

INPO's five functional divisions will be: Training and Education; Criteria Development and Analysis; Evaluation and Assistance; Emergency Preparedness; and Administration.

The Training and Education Division will review the curricula, lesson plans,



and other material currently used to train nuclear power plant operators and will identify and make available to all utilities the best of existing materials and approaches. The division will upgrade existing approaches when needed and will develop new material if none exists in a given area.

This division will accredit instruction systems for nuclear power operations technology and will certify instructors, assisting as necessary in their training and development of teaching skills. In his briefing on INPO before ACRS, Lee emphasized that "INPO will not train operators; it will train trainers."

The division will also conduct workshops and seminars for various utility employees, including executives. The executive program will stress management responsibility and philosophy on safety and reliability, relations with regulatory and government agencies on public safety, and crisis management and communication with the public and regulatory agencies.

The Criteria Development and Analysis Division will develop, through studies and analysis, the benchmarks that will be used to evaluate nuclear plant operations. It will also identify training needs and will develop and evaluate training techniques. Studies that might be conducted in this area include the adequacy of training simulator models and techniques of simulator use; the effectiveness of advanced instructional methods, such as computer-aided instruction; and psychological and physiological studies, such as shift rotation, attentiveness, and stress.

In close coordination with NSAC, this division will review and evaluate the Licensee Event Reports that utilities submit to NRC when reporting any malfunction or off-design incident at a nuclear plant. INPO will study these reports to identify what Lee termed possible "precursors of future events." INPO will feed back to the utilities lessons learned from these analyses and will incorporate the lessons in the training programs made available to utilities.

The Evaluation and Assistance Division will be responsible for organizing the evaluation teams that will visit nuclear utilities, probably annually, to evaluate their operations and provide assistance in improving their operations. Areas to be covered in an evaluation include management and organization; plant operating practices; training and qualifications; technological support; maintenance practices and material condition; human factors aspects of designs, arrangements, and practices; radiological controls; emergency preparedness; procedures, documentation, and administration; and in-house audit and quality assurance practices.

The Emergency Preparedness Division will be responsible for establishing what Lee called a recovery team, which he likened to a military reserve unit—a group of experts in various fields who could be available to assist a utility in an emergency. Lee noted that INPO would periodically drill such a team. The division will also list emergency equipment, its location, and the person to contact concerning its availability.

One of the early tasks of this division will be to assure implementation of the Nuclear Power Plant Emergency Response Plan developed by the Emergency Response Planning Subcommittee of the Atomic Industrial Forum's Policy Committee on Follow-Up to the Three Mile Island Accident. The plan provides a framework within which utilities can structure a specific recovery organization for each operating reactor.

The presentation of INPO's mission and structure drew some positive reaction on Capitol Hill. Congressman Douglas Bereuter of Nebraska, a member of the House Interior and Insular Affairs Committee, for example, said that INPO "sounds to be an exceptional idea."

Mutual Insurance Plan

The third major industry initiative taken in light of the TMI accident is a plan being considered for a mutual insurance arrangement that would provide utilities with an indemnity payment to cover part of the cost of replacement power in the event a plant is shut down for an extended period following an accident.

"Property and liability insurance for nuclear power plants have existed for years," explained John Selby at the House Energy Research and Production Subcommittee hearing on September 19. "However, no protection has been available for the cost impact of the long-term loss of a low-cost baseload generating plant."

In his September 2 testimony before the House Interior Committee's Subcommittee on Energy and the Environment, A. J. Phister noted, "It is anticipated that participation in the Institute of Nuclear Power Operations will be a condition of obtaining such insurance."

Only Phase One

Utility representatives describing their post-TMI efforts were adamant in their assertions that much remains to be done, and will be done.

"I want to assure you that even with the major steps that have been taken, we recognize we are still in Phase One," said Selby. "All the efforts to preserve an adequate electricity supply system for the next generation and beyond depend upon a complete and adequate response to the lessons of Three Mile Island. We will do our part to adequately and efficiently provide electricity at a reasonable cost by using nuclear energy and, at the same time, provide protection for the health and safety of the public." ■

NSAC Tracking Equipment Failure

NSAC combs through data on plant availability.
GPU estimates TMI-2 recovery at $400 million.

The Nuclear Safety Analysis Center (NSAC) is mounting a major program as part of the broad effort to prevent another nuclear power plant accident similar to the one at Three Mile Island Unit 2 (TMI-2).

To try to spot trends in equipment malfunctions and failures and any other off-normal occurrences in nuclear power plants, NSAC is undertaking a broad program of combing through all available plant data and Licensee Event Reports that NRC requires for any off-normal incident. The program will identify and examine in greater detail those events considered significant. Significance is to be judged on the basis of potential recurrence with serious safety or financial consequences or whether an event might be a potential precursor to a chain of events having such consequences.

There are numerous sources of such data. NRC publishes a monthly report on nuclear plant operating and outage statistics; the regional Electric Reliability Council reports on generating availability; and the Nuclear Plant Reliability Data System reports on equipment reliability. This material will be examined in great detail. In addition, the four reactor suppliers will contribute data, and NSAC will let four contracts for a review of reliability and equipment failure data.

Significant information or trends will be communicated to the utilities concerned. ■

Decontaminating TMI-2

In related work, a preliminary study to prepare recovery plans for reentry and decontamination of the TMI-2 containment building has been completed for GPU Service Corp. by Bechtel Power Corp.

While emphasizing that it is still preliminary (especially in the light of the uncertainties about the actual conditions inside the containment building) the study concludes that for planning purposes, return to service of TMI-2 can be targeted for mid-1983.

The study estimates the decontamination and reactivation of the plant will cost about $320 million, including $80 million for contingencies but excluding $60–$80 million for a new core. GPU has added $25 million to the proposed contingency budget item, bringing the total cost of putting TMI-2 back on-line to about $400 million.

The Bechtel report offers an assessment of the physical condition of the containment building (which has not been entered since the accident) and the estimated degree of damage. It outlines preliminary plans for reentering and carrying out the decontamination work.

A suggested schedule of major milestones in the recovery work (plus or minus six months) is included. Such a schedule, of course, is contingent on timely approvals by local and federal agencies. It shows reentry to the containment building in spring 1980; the reactor vessel opened, head removed, and core damage assessed in spring 1981; decontamination completed in summer 1982; evaluation completed on the feasibility and advisability of return to commercial operation in fall 1982; and restart, if approved, in summer 1983.

GPU is considering a slightly earlier entry into the containment building—sending a specially equipped and trained technician into containment in December 1979 to obtain more detailed data on conditions inside as an aid in selecting the decontamination technique to be used and in planning subsequent recovery efforts. ■

Progress in Wind Power Picks Up

If the current rate of progress in wind energy hardware development continues as planned, wind will be the first solar-electric technology available for utility use on an economic basis.

This is but one of a number of important conclusions reached during a workshop coordinated by EPRI's Solar Energy Program in March of this year on the status of large-scale wind systems for utility applications. The second in a series of seven workshops in 1979 sponsored by the DOE's Wind Systems Branch, the session drew over 120 representatives of utilities, the federal government, universities, and private industry. Other important findings included the following.

- Several years' field experience will be required before a clear picture of wind generation's prospects can emerge.
- Both wind energy resource and wind turbine generator siting considerations need to be much better understood before wind generation can play a significant role, regardless of success in hardware development.
- The most immediate priority for wind turbine generator development efforts is the conclusive demonstration of machine reliability, acceptable performance, and tolerable operating and maintenance costs.

According to Edgar A. DeMeo of EPRI's Solar Energy Program, it is also clear that electric utilities, as prospective users of wind power generation, are eager to obtain timely information on progress in wind development efforts. DeMeo says this stems from an emerging realization that a solid base of information is being assembled through DOE and other programs and that early experience has been encouraging.

One of the two main thrusts of EPRI's wind energy activity is to develop a strong communication link between hardware development projects and the electric utility industry. EPRI is sponsoring projects that foster direct interaction between wind R&D activities and utility industry personnel. These projects focus on wind turbine performance and wind energy resource assessment. EPRI is also assessing wind integration issues and developing methods individual utilities can use to appraise wind potential in their own service areas. These methods include attention to value estimates for wind generation (both capacity and energy value), economic goals for wind hardware, R&D recommendations, estimates of penetration, and inputs to related government programs.

The primary objectives of the March workshop were to report and discuss results and conclusions from major assessments of wind generation in electric utility networks, including economic and technical requirements for large-scale applications, and to promote feedback from the utility and manufacturing industries on present and planned activities in development, testing, assessment, and reporting.

Copies of *Proceedings: Workshop on Economic and Operational Requirements and Status of Large-Scale Wind Systems* (EPRI ER-1110-SR) are available from Research Reports Center. ■

Plummer Heads EPRI's Energy Analysis

James L. Plummer, director of corporate economics for Occidental Petroleum Corp. since 1976, has been named director of the EPRI Energy Analysis Department. In his new position, Plummer will be responsible for planning, implementing, and managing a broad program of research analyses relating to energy supply and demand for EPRI.

In making the announcement, René Malès, director of EPRI's Energy Analysis and Environment Division, described Plummer as "unusually well qualified for the responsibilities of this position. His educational and practical background includes economics, specific experience in the energy field, and work experience in the environmental area."

Before joining Occidental, Plummer was manager of energy studies for the National Science Foundation. Prior to that he was with the U.S. Office of Management and Budget, the U.S. Environmental Protection Agency, and the U.S. Agency for International Development in Bogotá, Colombia. Between 1967 and 1970, he was an assistant professor of economics at the U.S. Air Force Academy.

Plummer holds a PhD in economics from Cornell University, a BA in economics and an MBA from the University of Southern California. He has published two books, as well as articles in various trade magazines and professional journals, and is the founder and current president of the International Association of Energy Economists. ■

Plummer

Evaluating the Hazard of Solid Waste

EPRI's Environmental Assessment Department has undertaken an evaluation of a chemical extraction procedure for judging the hazardous nature of solid waste.

The extraction procedure to be studied was previously devised by the U.S. Environmental Protection Agency. Evaluation by EPRI is being carried out in two phases. Phase 1, which is now complete, focuses on the reproducibility of the extraction procedure. Phase 2 will consider its sensitivity to modifications in laboratory procedures.

Requests for data or additional information should be sent to R. M. Perhac, acting director, EPRI Environmental Assessment Department.

CALENDAR

For additional information on the EPRI-sponsored/cosponsored meetings listed below, please contact the person indicated.

JANUARY 1980

15
Regional Review: Fossil Fuel Power Plants Department
Jacksonville, Florida
Contact: B. G. McKinney (615) 899-0072

16
Regional Review: Fossil Fuel Power Plants Department
New Orleans, Louisiana
Contact: B. G. McKinney (615) 899-0072

MARCH

9–13
Second International Symposium on Gaseous Dielectrics
Knoxville, Tennessee
Contact: Don Bouldin (615) 574-6200

Japanese Environmental Scientists Visit

An update on the environmental aspects of power plant cooling operations in the United States was the purpose of a recent visit to EPRI by a group from the Central Research Institute of Electric Power Industry (CRIEPI) of Japan. Meeting with members of the EPRI Environmental Assessment Department were (from left) Shin-ich Senshu, director, Civil Engineering Laboratory, CRIEPI; Shigeru Shimo, vice director, Aquatic Biology Department, CRIEPI; Kazuyasu Nemoto, assistant director, Japan External Trade Organization; and Michiyasu Kiyono, marine biologist, currently with EPRI on an exchange program with CRIEPI.

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

FUEL CELLS

The EPRI Fuel Cell Program comprises two major activities. The fuel cell systems project group is expediting the commercial introduction of fuel cell power plants, with the current focus on phosphoric acid cells capable of a 9300-Btu/kWh heat rate for use in dispersed power plants. The advanced fuel cell technology project group is developing the fuel cell components required to improve power plant heat rates to 7500 Btu/kWh. Program and project background has been discussed in previous EPRI Journal *articles (June 1978, p. 34; November 1978, p. 6).*

Fuel cell systems

The major demonstration project in fuel cell systems is intended to culminate in an operational test of a 4.5-MW fuel cell module on the Consolidated Edison Co. system in New York City in 1981 (RP842). During the past year progress was made in several key areas: Final siting approval was received from the city's Board of Standards and Appeals; fabrication of the power plant module is nearing completion; site preparation is well under way; and major equipment is being installed at the site (Figure 1). A problem was encountered with the design and fabrication of the advanced formed-plate heat exchangers used in the power plant. Although now resolved, this problem delayed installation of the module by nearly one year. Equipment delivery is to be completed late this year, and checkout is to start early next year. The 2200-h validation test will be completed in early 1981.

The next critical step toward commercialization of the phosphoric acid fuel cell is being planned. EPRI, DOE, and several utilities are considering funding a 3½-year, $50 million program to complete the design, specification, and technical verification of a commercial prototype power plant. Based on an improved version of the 4.5-MW module, this plant would provide the needed bridge between the demonstrator and commercial hardware.

Two efforts to assess fuel cell applications and commercialization approaches have recently been initiated. First, EPRI is assisting the industry in forming a fuel cell users group, an association of utilities with an interest in the commercial use of fuel cell power plants. This group will work with manufacturers, EPRI, and the government to define requirements, develop a viable commercial power plant specification, and define utility roles in commercializing the technology. Second, an effort is under way to identify and evaluate viable commercialization scenarios (RP1677). These efforts parallel the technological efforts in an attempt to move the first-generation fuel cell to commercial status by 1985.

Identifying major opportunities for the application of fuel cells and the benefits (or penalties) of these applications has been an important objective of the Fuel Cell Program. Fuel cell power plants could accrue significant credits if sited near thermal loads that could effectively use the cells' reject heat. A

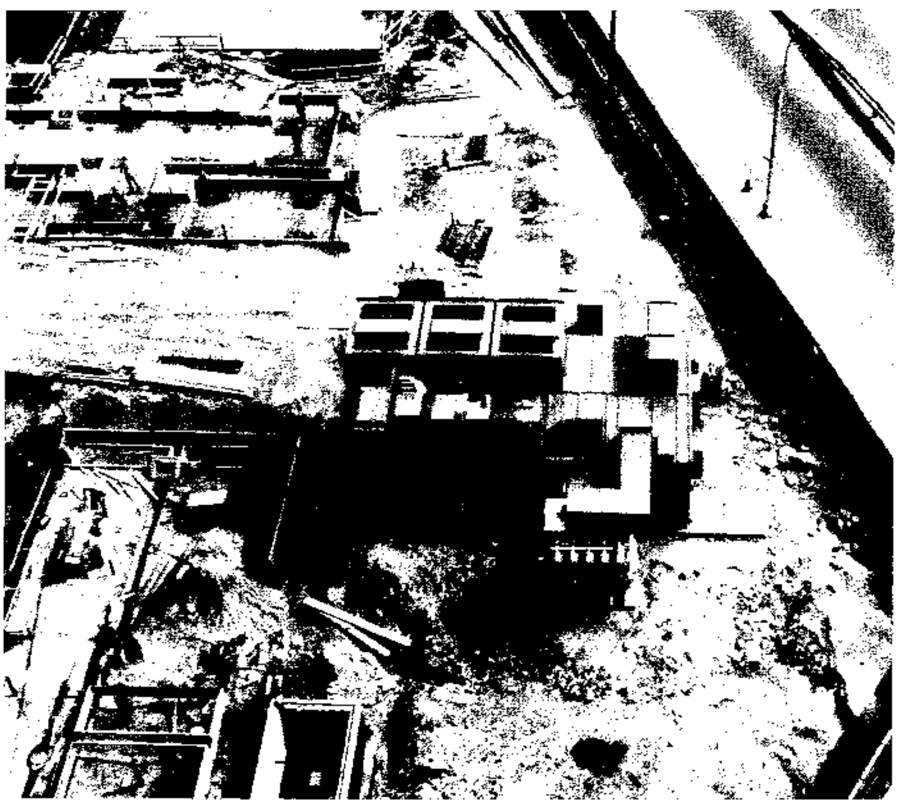


Figure 1 Installation of the 4.5-MW fuel cell demonstration module on Con Edison's system in downtown New York City.

study completed recently by Mathtech, Inc., confirmed that the fuel cell is well suited for such dual energy use systems (DEUS), that is, systems in which both the electric and the thermal output (reject heat) of a prime mover are used (RP1135). Although several other technologies could qualify for DEUS application, the fuel cell's environmental compatibility permits siting in metropolitan areas very close to the thermal need. Further, recovering the heat at usable temperatures does not degrade the efficiency of fuel cells, in contrast with presently used devices, such as extraction turbines. The fuel cell thus appears uniquely suited to make the best possible use of increasingly scarce and expensive fuels.

A series of projects on power plant integration aims to expand applications and markets by developing techniques that will enable fuel cells to use a wide range of fuels, including future utility fuels derived from coal (RP1041). One specific approach is to couple a novel steam reformer being developed by Toyo Engineering Corp for processing residual oils with a secondary adiabatic reformer being developed by United Technologies Corp. (UTC) and others. This hybrid processor concept was identified in 1978; if it is successful, a 6% improvement in heat rate and the use of middle distillate fuels from petroleum or coal should be possible even for first-generation fuel cell systems. Efforts are under way at Toyo and UTC to verify this concept; testing of a variety of coal-derived liquid fuels has also been initiated at UTC. Very preliminary results from tests using the lowest-quality fuel available—a solvent-refined coal wash solvent with 77% aromatics, 0.24% sulfur, and an end boiling point of >1000°F (538°C)—have exceeded expectations, suggesting that coal liquids may be easier to process into fuel-cell-grade fuels than originally thought.

Molten carbonate fuel cells, though perhaps five years behind phosphoric acid technology, are candidates for advanced fuel cell systems, particularly when integrated with coal gasification. DOE has initiated a $15 million-a-year program to expedite availability of the molten carbonate fuel cell in which a full-size (~500-kW) stack, based on state-of-the-art cell technology, will be developed and verified by 1982.

EPRI has two project groups that complement the DOE program (RP1273 and RP1085). In a three-year effort under RP1273, a 15–20-kW stack will be developed, fabricated, and tested; the stack will then be interfaced with an advanced fuel processor (from RP1041) in a breadboard system. This integration effort will precede the DOE program, defining (and resolving) issues related to systems interfaces and stack design, manifolding, manufacturing tolerances, and the like. Construction of the 20-kW stack will be completed in 1980. Progress under RP1085 is discussed below.

Advanced fuel cell technology

To achieve the goal of a 7500-Btu/kWh heat rate for advanced fuel cell power plants, individual cells must operate at a voltage of 0.78 Vdc (versus 0.63 Vdc required for the 9300-Btu/kWh heat rate of first-generation technology). This cell voltage must be attained at power densities of at least 150 W/ft² (1615 W/m²) to keep cost low and must be maintained for over 40,000 h to demonstrate adequate endurance in utility service. These are technical targets for advanced fuel cell technology projects.

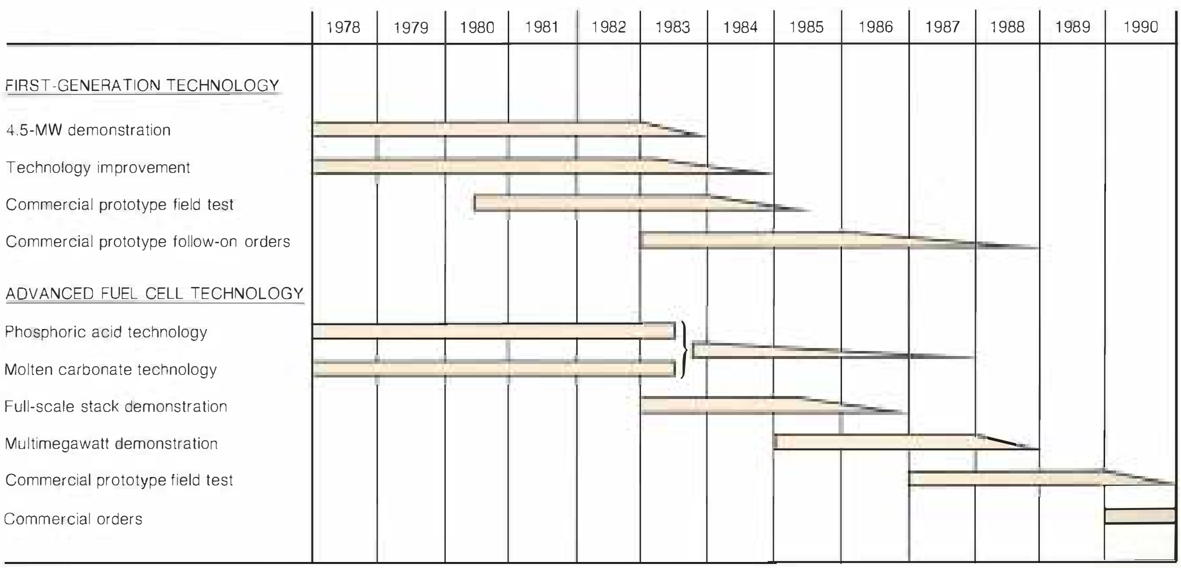


Figure 2 Time line for fuel cell development. First-generation cells are based exclusively on phosphoric acid technology. Both phosphoric acid and molten carbonate cells are being developed under advanced systems research; in 1983 it will be decided whether to focus work on one or the other or continue development of both advanced technologies.

Another effort is attempting to solve the corrosion and kinetic problems that limit the performance of present phosphoric acid fuel cells (RP1200). Two promising results have been recently produced: Carbon substrate materials have been identified that appear compatible with 40,000-h endurance at the required cell voltage and temperature; and platinum alloy catalysts have been operated experimentally at higher performance than the platinum catalysts used in state-of-the-art cell technology. While these results are preliminary, they suggest that improved phosphoric acid heat rates are feasible and may be easier to achieve in practical cells than originally suspected.

To date, molten carbonate technology has been the main focus of EPRI's advanced fuel cell efforts. Under the molten carbonate project group (RP114 and RP1085, to be combined in 1980 under RP1085), system integration efforts are being conducted in addition to cell technology development. A 1-kW stack, fabricated and tested this year under RP114, confirmed that new proof-of-principle cell configurations can overcome earlier limitations in thermal cycling. So far, the stack has successfully completed five thermal cycles over ~2000 h of test time. Important results of RP1085 include definition of integrated power plant–coal gasifier power system configurations with projected heat rates as low as 6800 Btu/kWh (coal to ac power); identification of low sulfur tolerance as a characteristic of current molten carbonate fuel cells (sulfur content of the fuel must be maintained below 1 ppm); and definition of potentially low-cost cell configurations capable of thermal cycling.

In a recently initiated project group, new fuel cell concepts with the potential for heat rates below 7500 Btu/kWh will be investigated (RP1676).

Outlook for the future

The future of the electric utility fuel cell will be influenced significantly by the magnitude of the national RD&D effort during the next several years. The DOE fuel cell program seems to be stabilizing at a budget of $30–$40 million a year, split between phosphoric acid and molten carbonate technologies. The emergence of the Gas Research Institute (GRI) and its $2–$3 million-a-year program on phosphoric acid fuel cells complements the $6–$7 million-a-year EPRI effort in phosphoric acid. Although the GRI program is aimed at smaller, 40-kW power plants, the fundamental cell technology is very similar to that being developed under RP842. Other fuel cell R&D efforts total about $10 million a year and consist primarily of activities supported by the Department of Defense and by individual gas and electric utilities.

Thus the national fuel cell effort is now at $50–$60 million a year, with the government taking the lead in both first-generation and advanced technologies. At this level the outlook is excellent for achieving commercial feasibility of first-generation fuel cells by 1982–1983 and making substantial progress toward advanced-technology targets during the 1980s (Figure 2). Before commercialization can be completed, however, the total national funding level will need to approach $100 million a year for a period of three to four years. It is not clear at present that such a commitment will be made, although recent legislation introduced in the Senate does propose major funding for fuel cell commercialization. *Program Manager: Arnold Fickett*

COAL CLEANING

EPRI's objective in coal-cleaning R&D is to provide a uniform-quality fuel while maximizing Btu yield and minimizing cost. The ash content and variability of run-of-mine coal have increased steadily with the introduction of continuous-mining equipment and various new mine safety regulations. This has led to lower availability and reliability in conventional pulverized-coal boilers. Coal cleaning offers a way to improve boiler operation by reducing slagging and fouling, and in many cases, it helps plants meet environmental regulations without scrubbers. Reduction of ash-forming minerals also reduces transportation costs.

Combined coal cleaning and FGD for new plants

Coal cleaning has been used extensively as an alternative to flue gas desulfurization (FGD) to meet state implementation plans in cases where moderate washing can reduce the coal's sulfur content by 20–40%. It was uncertain whether the more stringent SO_2 regulations resulting from the Clean Air Act Amendments of 1977 would eliminate coal cleaning as an option for new pulverized-coal boilers. EPA originally proposed a revised new-source performance standard that required 85% SO_2 removal; this was later revised to a sliding scale of 70–90% SO_2 removal in the final standard promulgated in June 1979. As a result of this standard, FGD will be required on all new coal-fired boilers. A study has recently been conducted for EPRI by Bechtel National, Inc., to determine the cost effects of using coal cleaning in combination with FGD in seven hypothetical power generation cases (RP1180-2).

Three levels of coal preparation were used in the analysis—no cleaning, partial cleaning, and intensive cleaning. Two-unit 1000-MW power plants were assumed to operate to 70% average load factor. Seven diverse combinations of coals and plant locations were evaluated, and SO_2 control was designed for 85% removal based on 24-h averaging.

The results of the study showed that in six of the seven cases, the overall capital cost estimates were lower with coal cleaning plus FGD than with FGD alone; these decreases ranged from 0.1% to 3%. On the basis of 30-year levelized cost estimates, the busbar cost savings from use of clean coal offset the incremental cost of cleaning in five of the seven cases. Savings realized were up to 2 mills per net kWh and averaged 0.8 mill per net kWh for the five cases where coal cleaning plus FGD was estimated to be cost effective. In all cases the levelized cost of clean coal was only 1–3 mills per net kWh higher than raw coal. These estimates are considered conservative, inasmuch as such economic benefits as improved availability and operability were not included because of insufficient quantifiable data.

The study noted the following impacts of using clean coal.

- Reduced bulk in coal transportation
- Lower coal burn rate for firing equipment
- Decreased fly ash loading in electrostatic precipitators
- Altered ash fouling and slagging tendencies
- Relaxed requirement for SO_2 removal by FGD because of lower coal sulfur content and improved heating value
- Decline in production rate of FGD sludge
- Improved fuel uniformity (less sulfur and ash fluctuation), allowing less conservative equipment design margins

The cost benefits of using clean instead of run-of-mine coal were estimated for the following components of the power generation system: coal transportation, power plant (excluding FGD and waste disposal), FGD, and waste disposal. Improved availability will likely result as abrasive minerals are removed that aggravate equipment wear and contribute to tube failures and thus to plant downtime. A more uniform fuel will allow better steam generator and FGD system control. Reduced tube wastage and improved boiler efficiency may also result from the use of a more uniform fuel.

Each case must be examined specifically because of differences in coal composition and in the resultant effects on the system. In the cases studied, ash content was reduced 10–70% and up to 35% of the sulfur was removed. Heating value was upgraded by 1.3–26%. The capital requirements for the 14 coal-cleaning plants ranged from $15 million to $37 million (mid-1978 dollars). For minimal cleaning, the capital requirement represented about 2% of the total capital cost for an equivalent 1000-MW pulverized-coal plant, and for intensive cleaning, 3–4%.

This study shows that utilities planning new boilers should investigate the combined coal cleaning–FGD approach.

Stone & Webster Engineering Corp. recently completed a study for EPRI on the impact of cleaned coal on power plant performance and reliability (RP1030-6). Existing operating data from plants using run-of-mine coal and from comparable plants using clean coal were examined. Power plant experience with clean coal was found to be limited, and the data analysis did not produce results sufficient to quantify the impacts of coal quality on power plant performance. The study did point out the need for producing an acceptable moisture content with washed coal. It also concluded that to achieve the maximum improvement in boiler efficiency and station heat rate possible from the use of washed coal, a power plant must be operated to take advantage of all benefits (e.g., reduced boiler cleaning). The fact that there were not enough data to quantify the benefits of clean coal points up the need for well-designed data collection tests on boilers that are scheduled to be converted to washed coal.

Coal-cleaning development and demonstration

If the cost of clean coal is to be reduced, the Btu yield increased, and the product quality improved, R&D is required in instrumentation and in three plant operations—liberation, separation, and dewatering. Unit operation improvement at bench and test-stand levels will be developed in various projects. These improvements will then be demonstrated in the EPRI 20-t coal-cleaning test facility currently being constructed in Homer City, Pennsylvania. The test facility will be very flexible and can be configured to simulate present or proposed cleaning-plant operations. Various equipment and process variables may be manipulated to determine impact on clean coal quality and Btu recovery. Thus, an optimized flow sheet may be approached for a given coal.

Conventional water-based cleaning requires that run-of-mine coal be crushed so that coal particles can be separated from pyrite and ash-forming minerals. McNally-Pittsburg Mfg. Corp. and Pennsylvania State University are collaborating to improve the crushing, grinding, and liberation of coal from pyrite and ash minerals (RP1338-3). They will demonstrate computer models developed to select viable size-reduction circuits and predict size reduction and pyrite liberation. Use of these models will minimize overgrinding and conserve energy.

Separation of the clean coal particles from refuse is being improved by both gravity separation and flotation techniques. Heavy-media cleaning of fine coals has been studied by Kaiser Engineers, Inc., under RP1338-2, and the project has now been expanded to cover the problem of recovering the magnetite media from fine clean coal and fine refuse (with Eriez Magnetics).

Automatic control of heavy-media processes will be studied by Envirotech Corp. (RP1338-1). In this project a 200-t/h heavy-media cyclone plant will be completely instrumented and run under computer control. Plant performance under automatic control will be compared with that under manual control. The project is expected to demonstrate the feasibility of automatic operation and provide economic justification for higher levels of instrumentation in coal-cleaning plants.

The separation of pyrite from coal by flotation and the application of flotation to oxidized and low-rank coals are being investigated by Envirotech and PSU under RP1338-4. If successfully developed, these techniques will find large-scale application in the processing of fine coals for power generation.

Dewatering is becoming increasingly important in coal cleaning as larger quantities of fine coal are produced during mining. Present techniques for dewatering fine particles, although presently adequate, need a great deal of improvement. A project combining surface chemistry with the currently available technology of filtration and centrifugal dewatering is being finalized.

The basic objective of this project, to be carried out by the University of California at Berkeley, is to reduce the moisture content of 28 mesh × 0 fines from the present level of 22% to about 10%. Successful development of this technology will assist in closing the water circuits in coal plants and in reducing dependence on thermal drying. *Program Manager: Kenneth L. Clifford; Project Manager: Randhir Sehgal*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

DUCTILE FRACTURE MECHANICS

Currently available analytic methods greatly underestimate the margin to failure for flawed structures of ductile materials (such as those used for pressure vessels and piping in nuclear plants) because they equate the onset of crack extension to structural failure. In reality, an extended period of stable crack extension often precedes failure, and to obtain accurate failure predictions, crack extension and final instability must be analyzed, as well as the onset of crack growth. The required ductile fracture mechanics methodology has been under development by EPRI since 1975, and recent results suggest that simple procedures may soon be available that will enable designers to predict accurately the behavior of flawed, ductile structures (RP601, RP1237).

All engineering structures contain flaws, regardless of the care exercised in fabrication. These flaws can range in size from microstructural discontinuities (inclusions) to large flaws developed during fabrication or induced by service loadings. To ensure structural reliability it is necessary to define the maximum size of flaw that does not degrade a structure's performance and then remove or repair all larger flaws. To define the acceptable flaw size, a structural integrity analysis is required that accurately predicts the flaw-stress interaction for the structure under realistic service conditions. The impetus for the research described here is the fact that the analytic techniques currently available do not accurately predict the flaw-stress interaction under service conditions for pressure-retaining components in nuclear reactors. The available techniques are based on linear elastic fracture mechanics, which assumes that the construction materials fracture in an elastic, brittle manner. In reality, the materials used to construct the nuclear pressure boundary are ductile at service temperatures and can deform significantly before failure, even when flaws are present.

Another contradiction between assumed and observed material behavior is the sequence of fracture. Under the conditions of linear elastic fracture mechanics, structural instability (failure) is coincident with the onset of crack extension (initiation of crack growth). With ductile materials there is a certain amount of stable crack growth after initiation; during this period, load increases are necessary for additional crack extension to occur. Finally, structural instability is established by unstable crack growth. With current approaches, only the conditions for initiation of crack extension can be defined. Realistically, however, three conditions must be known: the conditions for initiation, stable growth (how much crack extension for a given increase in load), and crack instability.

Test data illustrating the three stages of ductile fracture are shown in Figure 1. For the ductile materials used in the fabrication of nuclear pressure-retaining components, the assumption that the onset of crack extension coincides with failure leads to a substantial underestimation of the true load-carrying capacity of flawed structures. To obtain accurate estimates of the margin against failure and the acceptable flaw size,

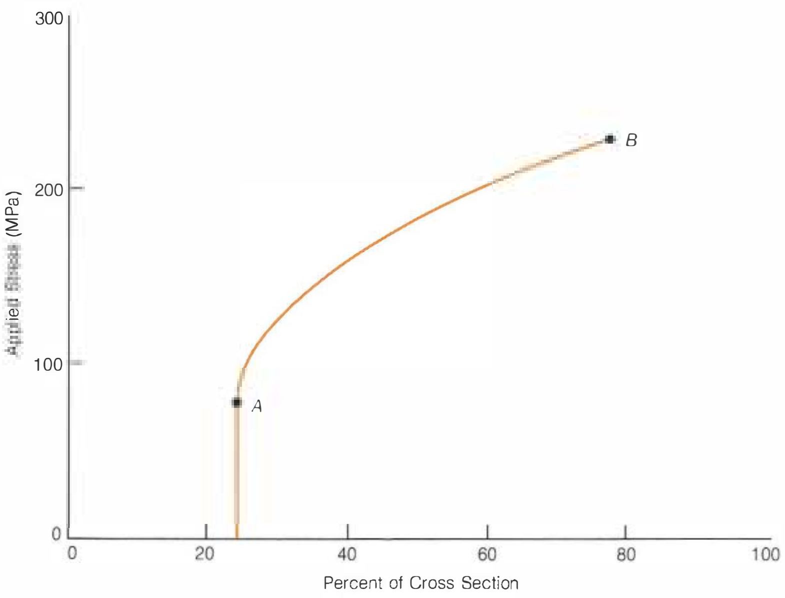


Figure 1 Test results illustrating the three stages of fracture for a flawed structure of a ductile material with an initial crack extending through 25% of the material's cross section: initiation of crack growth (*A*), stable crack growth (*AB*), and structural instability (*B*). Current analysis procedures would predict failure at *A* instead of *B*; that is, at a stress of about 80 MPa rather than the 210 MPa actually observed.

all three stages of ductile fracture must be considered in a ductile fracture mechanics analysis.

A project was begun in 1975 to develop an analytic methodology appropriate for predicting accurately the conditions required for the ductile failure of a flawed nuclear pressure vessel (RP601). The broad-application methodology of the type desired required the following analytic and experimental studies.

- Development of criteria for the onset of crack extension, stable growth, and instability under large-scale deformation conditions
- Development of a method for describing the elastic-plastic behavior of both the structure and the crack tip region
- Extensive laboratory- and large-scale experiments to reproduce the pertinent plastic flow and crack phenomena

The first task in RP601 was to amass information on a number of promising fracture criteria and to conduct laboratory experiments to determine the relationship between the measurable quantities—specimen load, displacement, and crack extension. Each fracture criterion was then evaluated by using it and two of the measured quantities to calculate the third. The correspondence between the predicted value and the actual measured value was an indication of the validity of the criterion. This process was repeated a number of times, and the "best" criteria were filtered out and verified with additional experiments that used several different specimen shapes with vastly different flow characteristics.

RP601 was successful in developing a methodology for predicting the onset of crack growth, stable crack extension, and structural instability (NP-701-SR). Unfortunately, the calculations necessary to apply the methodology to the flawed structures of interest require large computer programs, skilled operators, and relatively large expenditures of time and money. To circumvent these requirements, which would greatly reduce the value and general applicability of ductile fracture mechanics, RP1237 is seeking to develop a ductile fracture analysis procedure based on simple graphic or semianalytic procedures that yield results of acceptable engineering accuracy.

The approach being taken in RP1237 is (1) to develop a handbook-style compilation of fracture criteria solutions for fully plastic structural geometries containing cracks, (2) to combine the elastic solutions currently available with these fully plastic solutions to

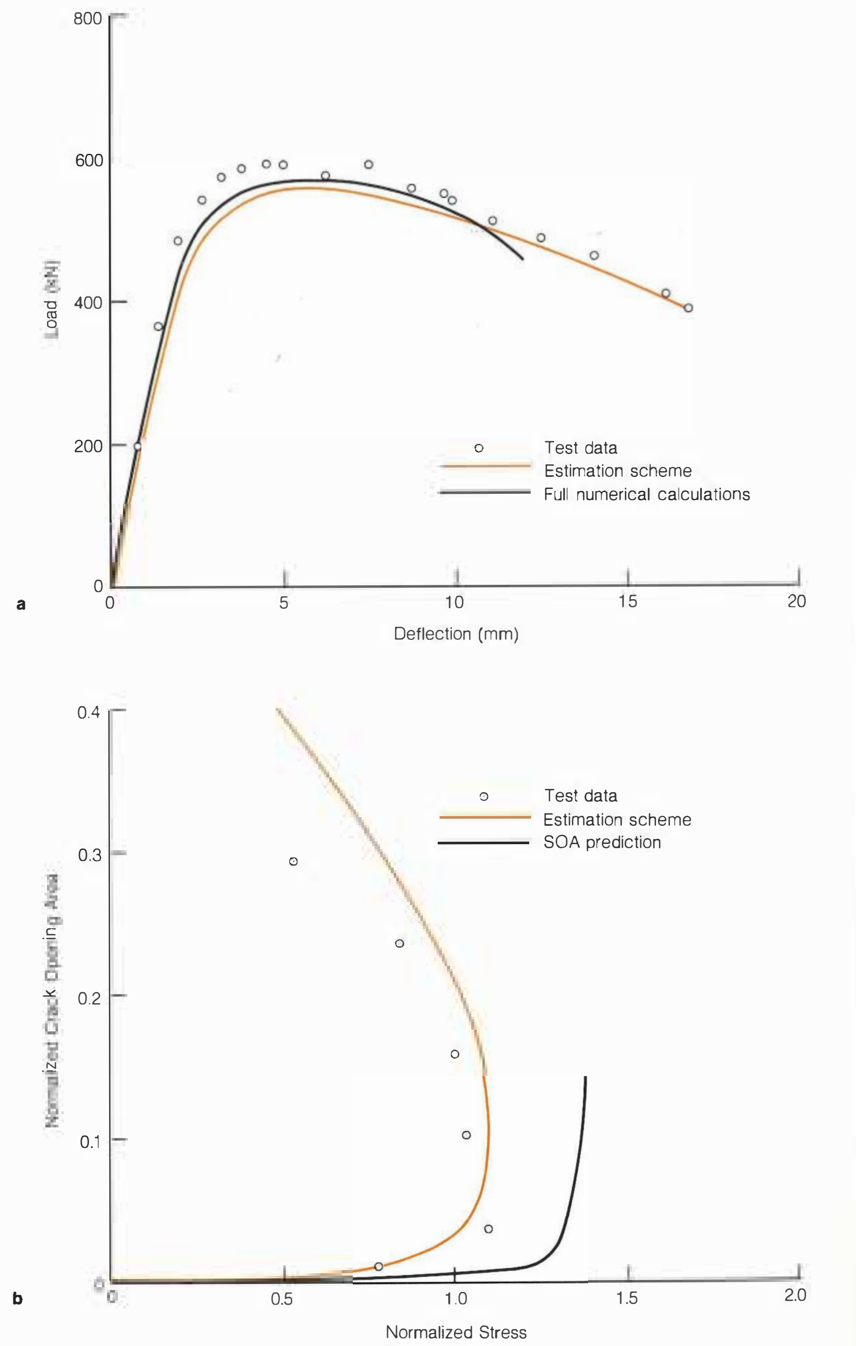


Figure 2 Comparisons of test data with predictions made using the ductile fracture estimation scheme.
(a) The load-deflection curve for a compact tension specimen of SA533B steel. The estimation scheme prediction compares favorably with the maximum load, which is reached well after initiation of crack extension.
(b) The crack opening area for a center-cracked panel of AISI type-304 stainless steel. The estimation scheme somewhat overestimates the area of the crack opening after maximum load is reached but is much more accurate than the state-of-the-art (SOA) prediction.

produce an estimate of the driving force for crack growth in flawed structures under realistic elastic-plastic conditions, and (3) to develop a simple method for predicting the three stages of ductile fracture by combining the driving force estimates with an appropriate measure of the fracture resistance of the material. The method used in this research is based on graphic comparison of the system driving force for crack growth with the crack growth resistance curve of the material, evaluated by using a standardized test method. This approach readily permits consideration of system compliance or stored mechanical energy. Three degrees of geometric difficulty are being considered in this research. The simplest is the standard fracture test specimen geometries, of which detailed numerical calculations are available for benchmarking purposes. The second level is that of generic structural components, such as longitudinally and circumferentially flawed cylinders, and the third level is a cracked-nozzle geometry.

Progress to date has been extremely encouraging. Figure 2 illustrates two examples of successful applications of the simplified ductile fracture analysis procedure. In each case, development of the analytic prediction required a few minutes' work with a hand calculator to develop appropriate driving force curves from the handbook solutions, the specimen dimensions, and the material stress-strain curve. Then a simple graphic comparison of these driving force curves with the previously determined ductile fracture resistance curve of the material gave the estimation scheme predictions shown in Figure 2, which in both cases show close agreement with the behavior actually observed. Similar agreement between prediction and experiment has been observed in all the validation tests conducted to date, which have included a wide range of test specimen geometries and material properties. It seems likely that further development will lead to the availability of a simple engineering tool of wide applicability that can be used by designers and regulators to make reliable estimates of the margin to failure of flawed structures of ductile materials and to set realistic limits for acceptable flaw sizes.

The present phase of RP1237 is scheduled for completion in early 1980, and it is anticipated that the first edition of the ductile fracture handbook, containing the fully plastic solutions developed during the first phase and examples of their use in predictive analyses, will be published by June 1980. *Project Managers: Theodore Marston and Robin Jones*

STEAM GENERATOR SIMULATION AND FLOW VISUALIZATION EXPERIMENTS

The steam generator in a PWR forms an important link between the primary loop, which acts as a nuclear heat source, and the secondary loop, which acts as a heat sink that generates steam to drive turbines for maintaining electrical grid load. The steady-state and transient thermal-hydraulic responses during daily load changes or during a reactor or turbine trip govern the steam generator's thermal behavior. The work described here is intended to provide information on such steam generator behavior under normal (steady-state) and off-normal (transient) conditions, and thus help support a safe and reliable PWR operation. These experimental efforts are supplying data for parallel work in steam generator code development and evaluation (RP684-1 and RP1066-1). They focus on the flow distribution, the phase separation mechanism, and the heat transfer characteristics of a natural circulation, U-tube steam generator. For testing purposes, a facility with a 1/7-scale model of a typical commercial U-tube steam generator has been built. Tests covering a wide range of normal operating conditions have been conducted. Code evaluation and operational transient tests are in progress.

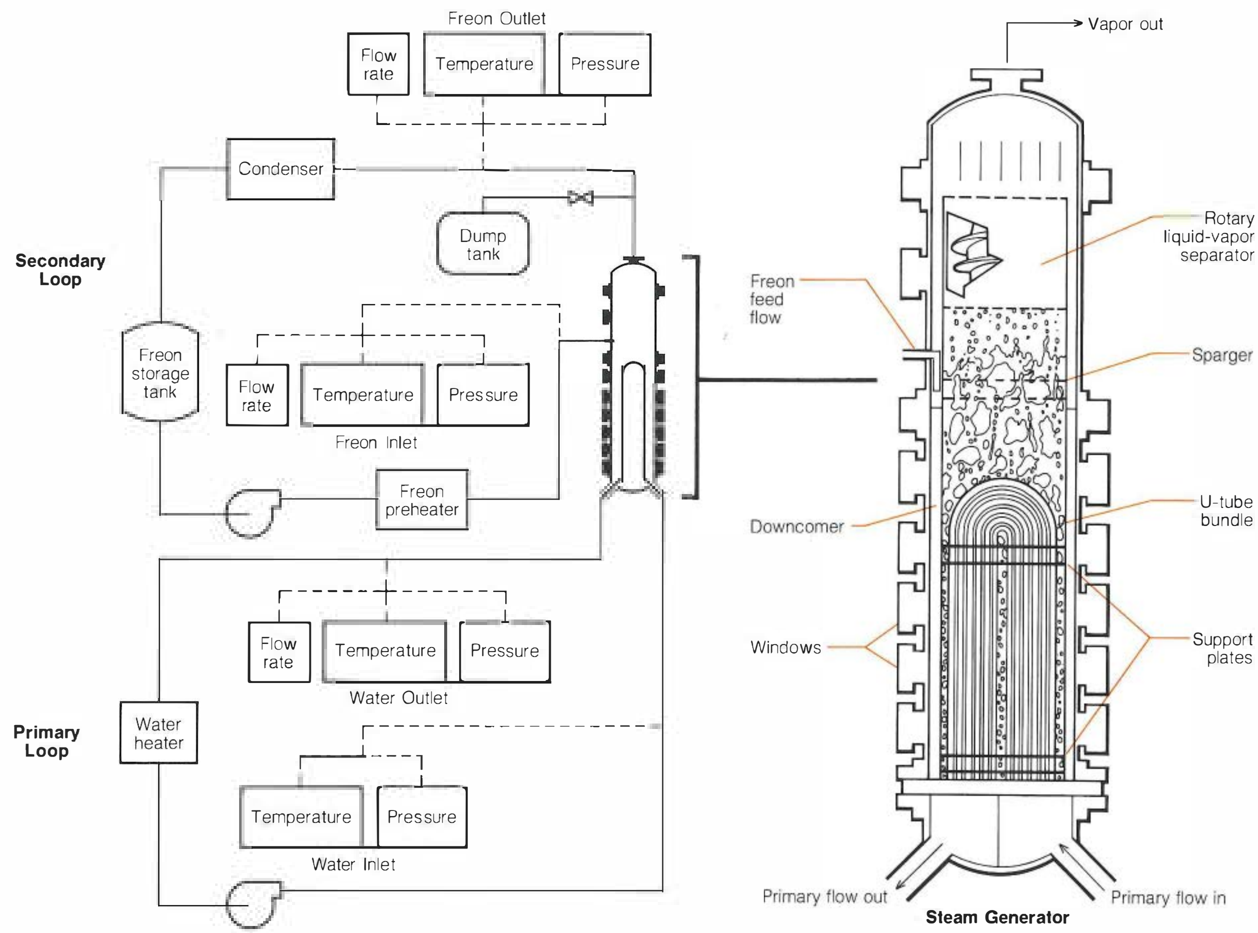
The performance characteristics of a U-tube steam generator are influenced by phase separation in natural circulation, asymmetric boiling, incomplete mixing caused by carry-over or carry-under, and mechanical separator behavior. Two-phase flows associated with these characteristics are very complex and are poorly understood for a variety of reasons. First, design information used by nuclear steam supply system (NSSS) vendors is derived from empirical experiments tailored to their specific designs, and such information is proprietary. Second, both global and local behavior of a U-tube steam generator are strongly coupled to the operating pressure boundary conditions, and therefore integral experiments are required for imposing proper pressure boundary conditions. Third, boundary conditions for crevice heat transfer and flow-induced vibrations are set by the global thermal-hydraulics; again, integral experiments are necessary to provide proper boundary conditions.

In this study, integral experiments are being conducted to provide a data base for evaluating thermal-hydraulic responses under both normal and off-normal conditions (RP1162-1). The data base will be used to evaluate steam generator codes by comparing code predictions with the appropriate integral test results. The test facility, with its 1/7-scale model of a typical commercial steam generator, provides an integral simulation of downcomer, U-tube bundle, riser, and separators. A schematic of the steam generator test facility is presented in Figure 3.

Table 1
TEST FACILITY DESIGN PARAMETERS

Parameter	1/7-Scale Model	Typical Steam Generator
Average length	2.2 m	17.5 m
U-tube diameter	1.91 cm	1.91 cm
Pitch/diameter ratio	1.41	1.41
Shell diameter	0.414 m	3.28 m
Number of tubes	76	3500
Heated surface area	10.03 m²	3675 m²
Wetted perimeter	10.42 m	430.3 m
Flow area within bundle	0.092 m²	6.444 m²
Hydraulic diameter (heated riser)	3.54 cm	5.99 cm
Mass flux scaling factor	1	1.16
Heat flux scaling factor	1	12.26
Typical heat flux	20 kW/m²	246 kW/m²
Power	200 kW (th)	900 MW (th)

Figure 3 Steam generator simulation facility; primary and secondary flow loops.



The general design features include an integral geometric similarity to typical U-tube steam generators, an overall modeling of steam-water behavior by using Freon in the secondary loop, visualization of flow regime development within the steam generator, and a provision for steady-state and transient tests. Table 1 lists the facility's design parameters and compares them with those of a typical commercial PWR generator.

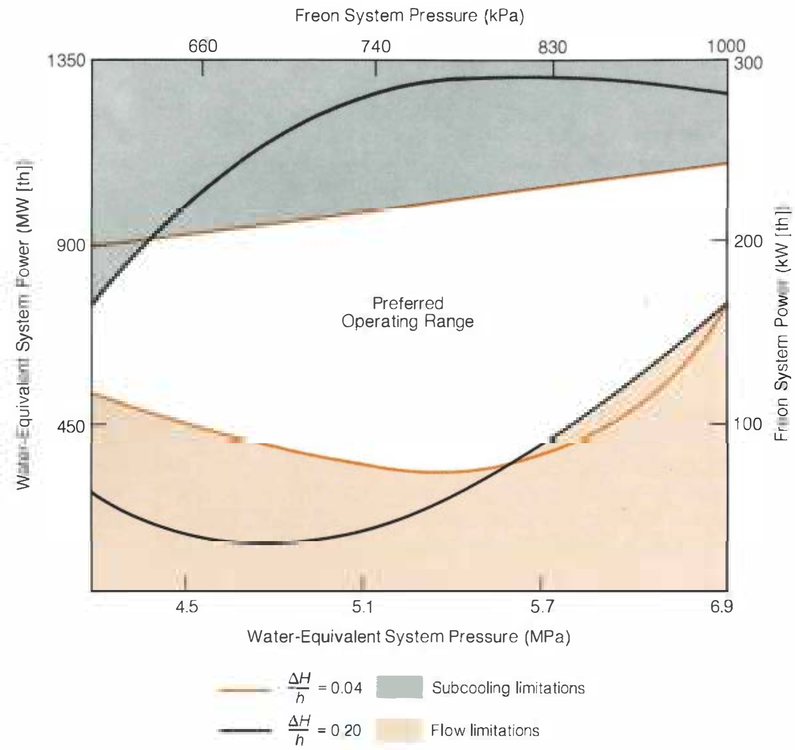
A series of steady-state tests has been conducted. The prototypical values simulated in these tests are as follows: system pressure, 4.5–7 MPa (650–1000 psia); thermal power, 700–1200 MW (th); circulation ratio (ratio of steam mass flow rate to total mass flow rate), 5–15; and tube diameter and pitch identical to those of a commercial system. Figure 4 shows the range of system parameters covered; the shaded area represents the present operating limits of the facility. An interim EPRI report describes the facility and performance limits (NP-1088), and a paper based on the steady-state tests was presented at the October 1979 International Conference on Boiler Dynamics and Control in Nuclear Power Stations.

The downcomer level in a U-tube steam generator is an operation control parameter. Present results indicate that the circulation ratio varies significantly with power for a range of downcomer levels. The overall heat transfer coefficient has also been obtained for a range of mass flux within the U-tube bundle at various downcomer levels. These values indicate a particular trend; that is, they tend to group according to the downcomer level.

Flow regime information is essential for accurate two-phase flow model development and analysis. Windows are provided at six axial locations for flow visualization. High-speed movies and still photography provide information on flow regime development, recirculating flows, boiling in the crevice, and carry-over and carry-under. Close-up movies taken near the crevice at the upper support plate indicate a preferential nucleate boiling in the crevice, an important finding for crevice heat transfer model development.

In contrast to extensive studies of the thermal-hydraulic performance of PWR fuel cores, steam generator studies are in the early stages. The optimal research strategy is to pursue experimental and analytic work in parallel, and EPRI has therefore initiated four other projects: an analysis of the steady-state and transient results, using the

Figure 4 Thermal-hydraulic performance of the steam generator simulation facility. ΔH = inlet subcooling; h = heat of vaporization.



advanced three-dimensional code URSULA (RP1162-2); special measurements under transient conditions (RP1162-3); local velocity profiles in mechanical separators (RP1162-4); and a study to determine the transient fluid-modeling parameters (planned). The information resulting from these efforts will also complement the thermal-hydraulic work of EPRI's Steam Generator Project Office (S133-1, S134-1).

In addition, in-house work is investigating natural circulation phenomena in steam generators, the potential of using the three-dimensional capabilities of the TRAC code for predicting steam generator behavior, and the on-line use of the URSULA code for test data prediction.

The next two phases of the research involve extensive experimentation under accident conditions, including loss of secondary feed and steam line breaks. These tests are extremely important for the safe operation of PWRs. *Project Manager: S. P. Kalra*

LOW-TEMPERATURE SENSITIZATION IN STAINLESS STEEL PIPE WELDS

A sensitized microstructure is one of the essential conditions for the intergranular stress corrosion cracking (IGSCC) of type-304 stainless steel. EPRI-supported research has demonstrated that the degree of sensitization in the weld-heat-affected zone of welded type-304 stainless steel piping increases with time at BWR operating temperatures. This increase may mean that IGSCC could occur at less extreme stress and environmental conditions than commonly thought necessary.

A problem that has significantly affected the BWR industry in the past few years has been the stress corrosion cracking of type-304 stainless steel pipe welds. Three conditions are considered essential for IGSCC to occur in BWR piping: a sensitized microstructure, a sufficient level of stress, and an environment that will facilitate IGSCC. Early in 1978 an EPRI research project was initiated with General Electric Co. to study fabrication-related sensitization phenomena in type-304 stainless steel (RP1072-1).

A sensitized alloy is one that is especially susceptible to intergranular attack. This sensitized condition is usually the result of thermal exposure in the 500–800°C range. The most widely accepted explanation for sensitization is the chromium depletion theory, which attributes the increased susceptibility to the formation of chromium carbide particles along grain boundaries, causing depletion of chromium from the adjacent matrix. The sensitization that occurs when type-304 stainless steel is welded is localized in the region adjacent to the weld, the weld-heat-affected zone.

In most cases the degree of sensitization that occurs during welding is not severe enough to result in IGSCC. However, the results of this project have shown that severe sensitization can occur at temperatures well below the normal sensitization temperature range if chromium carbide nuclei are present. This phenomenon has been referred to as low-temperature sensitization (LTS), and it is believed to result from the low-temperature (288°C) growth of grain boundary carbides that were nucleated during welding.

The potential effect of LTS is that for some alloy compositions, the degree of sensitization of welded BWR piping could increase with reactor operating time. An increased degree of sensitization can lead to a reduction in the required magnitude of the conditions essential for IGSCC (environmental conditions and stress). Consequently, previously benign conditions may become more likely to foster IGSCC with time. Knowledge of the details of LTS will help determine if the phenomenon is of concern for operating reactors and, if so, will provide a rational basis for devising a solution. If only certain alloy compositions are susceptible to this effect, these can be identified for selective inspection and repair or replacement. In this way extended outages for repair can be minimized.

To date, the existence of LTS has been confirmed in experiments with three different pipe welds and three different heats of type-304 stainless steel. The experimental confirmation has included stress corrosion testing and detailed microstructural studies by using scanning transmission electron microscopy. The results of all studies have been consistent with a nucleation and growth model. Chromium carbides are nucleated along grain boundaries during welding and grow at lower temperatures at a rate limited by the diffusion of chromium. The growth of the grain boundary carbides contributes to chromium depletion in the region adjacent to the grain boundaries.

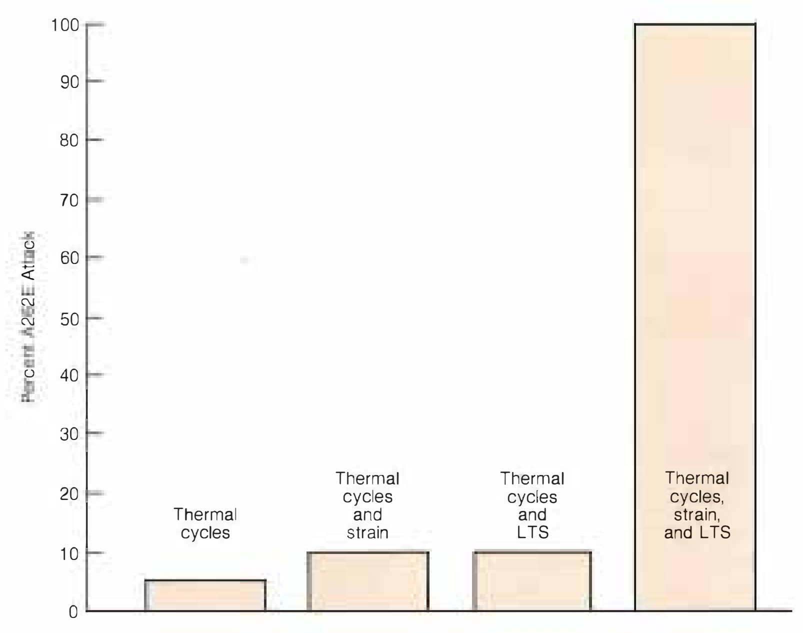
The most surprising result of this research is that the rate of LTS is far greater than can be accounted for by using known values for the diffusion of chromium through the bulk matrix of the material. For example, the activation energy for the diffusion of chromium through the bulk matrix of type-304 stainless steel is ~65 kcal/mole (~272 J/mole), whereas the apparent activation energy for the LTS process is ~40 kcal/mole (~168 J/mole). A lower activation energy means that it is easier for chromium to diffuse. At 40 kcal/mole, a significant degree of sensitization can occur at BWR operating temperatures in a reactor lifetime (less than 40 years), while it would require about 1000 years to achieve the same degree of sensitization at 65 kcal/mole.

Further research on this project has shown that these differences in activation energy may be due to physical changes in the weld-heat-affected zone that occur during welding, such as increased dislocation density. For example, the thermal simulation of welding alone will not produce susceptibility to LTS. However, if weld shrinkage (strain) is simulated at the same time, type-304 stainless steel becomes markedly susceptible to LTS. Figure 5 illustrates the synergistic effects of thermal cycles, weld shrinkage (strain), and LTS.

The recognition of LTS and its characteristic behavior has facilitated the selection of alternative materials for type-304 stainless steel. It is possible to simulate many years of reactor service in relatively short periods of time, thereby making it possible to screen out LTS-susceptible materials. It is also possible to detect heats of type-304 stainless steel that contain carbide nuclei but that could pass a conventional sensitization screening test for sensitization in the mill-annealed condition.

Finally, it should be noted that the existence of LTS does not mean that IGSCC will inevitably occur in all type-304 stainless steel BWR pipe welds. The appropriate stress and environmental conditions must also be present before IGSCC can occur. The exact effect of LTS on the stress and environmental conditions required to facilitate IGSCC is currently under study in a new EPRI project (RP1565-1). *Project Manager: M. J. Povich*

Figure 5 The bars represent the percent of attack in the acid copper sulfate test (ASTM–A262E) after various combinations of simulated welding thermal cycles, simulated weld shrinkage (strain), and low-temperature sensitization (LTS). Acid copper sulfate is known to attack stainless steel grain boundaries that are depleted in chromium; the greater the attack in A262E, the more severe is the chromium depletion and hence the degree of sensitization. A combination of strain and LTS (not shown) does not produce an attack in A262E.



R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DC STATIONS AND EQUIPMENT

Electrostatic dc fields in converter stations

Accurate instrumentation and meaningful measuring methods are needed to support the extensive current research on potential environmental effects from electric fields surrounding high-voltage lines and stations. The ultimate goal of such research is to predict the electric field strength that will exist around lines and within stations prior to the construction of new facilities. This is a particularly difficult problem for substations where the geometry is very complex. A method using scale models was recently successfully developed for ac substations under an EPRI contract with Ohio State University (EL-632, Vols. 1 and 2). As previously reported (*EPRI Journal,* October 1978, p. 67), EPRI initiated another contract with OSU that builds on the experience of the ac work for prediction of the ground level electrostatic field strength in dc converter stations (RP1097). Technically, this is a more challenging task because the dc field distribution is nonlinear and is affected by corona (primarily from dc line conductors in the vicinity of the converter station), and the measurement of electrostatic dc fields is much more difficult than the measurement of ac fields.

The corona phenomenon was observed in some early field tests that were conducted for identification of modeling parameters. Consequently, OSU researchers have devoted quite a bit of time to the basic work required to establish the feasibility of scale models for prediction of the electrostatic fields in converter stations. The first part concentrated on modeling short monopolar and bipolar line sections. Small-diameter stranded and solid conductors were studied in overhead line models. These model experiments were structured so that the laboratory results could be compared with the full-scale tests and measurements reported in the literature. In most cases there was a surprisingly good correlation between the model experiments and the reported results from full-scale tests. Even the effects of wind, humidity, and vegetation have been investigated, with results that compare qualitatively well with full-scale tests. Further, it was accidentally found that dust greatly affects the corona onset levels for conductors. This may explain some of the anomalies reported in the literature.

Researchers determined that the critical parameter for modeling is the corona onset value of the conductors. Some tests at voltage levels between 200 and 250 kV have been conducted on a full-size conductor sample. According to results of these tests, it now appears feasible to use scale models for prediction of ground level electrostatic fields in dc converter stations.

Another key element in the modeling work is the instrumentation probes needed for field measurements in the model. This type of instrumentation probe is not readily available and had to be built specifically for the model. The probe had to be very small so that it would not affect the fields and very sensitive because the field strengths in the model are small. The device that was constructed in cooperation with instrument suppliers is a miniature, vibrating-reed-type electrostatic field measuring probe.

It should be noted that most of the available instruments for measuring electrostatic fields can be affected by charged particles, which may become attached to the insulating surfaces close to the sensitive measuring probes. This necessitates frequent calibration and occasional cleaning of the probes.

In view of the very complex nature of the field distribution, it must be emphasized that the accuracy of the dc field strength predictions will be much less than that possible with ac field distribution in the completed project (RP753). However, at this time it seems probable that a successful field prediction method will be developed for dc converter stations. *Project Manager: Stig Nilsson*

Fault data acquisition system

The amount of data required for evaluation of a research facility such as the prototype dc link (RP213-1) is very large, and operators are unable to gather many types of needed data. It was therefore decided early in the project to use a computerized fault data acquisition system (FDAS) for the data collection. This system is intended to provide high-resolution data for analysis of potential equipment faults and system disturbances. However, the system should also be useful to the utility industry in general because the needs of an ac power system operator do not differ significantly from those of a converter station operator.

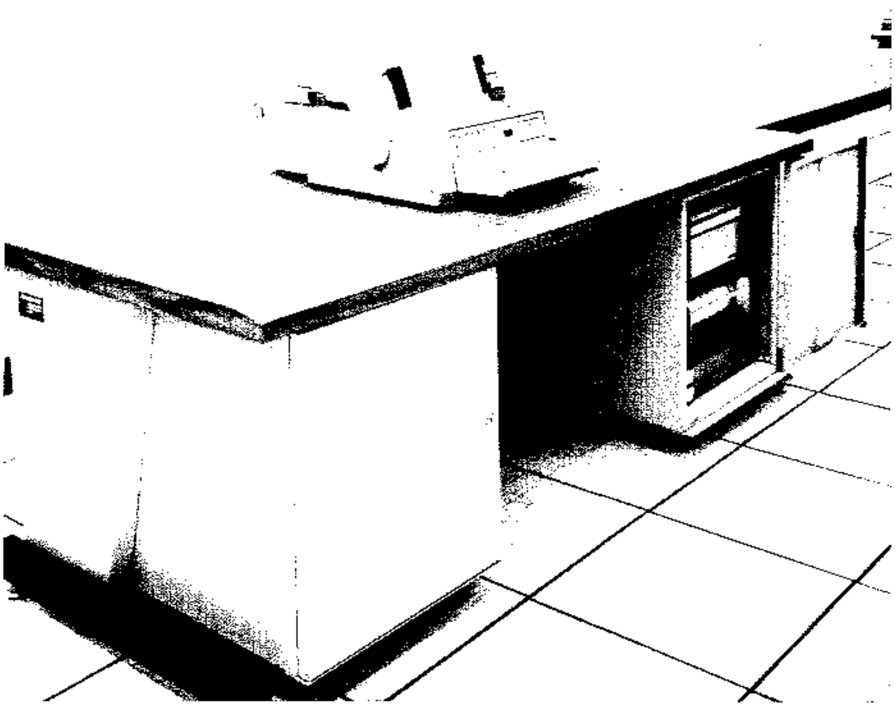
The main objective of a project with Boeing Engineering & Construction is to develop a system that will perform data logging, sequence-of-events recording, and oscillographic fault-recording functions (RP213-3). Although application of computers to these areas is not new, the ability to forward all the information to a remotely located operator, including full-bandwidth (1.6-kHz) oscillographic fault data, was not previously available. This was a system requirement to allow for future unattended operation of the prototype dc link. The development of the new data acquisition system was guided by the following specific requirements or assumptions.

- Sequence-of-events records and oscillographic-type fault records must be transmitted to the user within a reasonable time (2–5 min) after an event over normal voice-grade communication channels.

- No data of importance for analysis of faults should be lost because of a communication system outage.

- The clocks at the various data collection

Figure 1 Remote operator's console for a developed fault data acquisition system. The output device for oscillographic fault records is located in the right-hand side of the cabinet, and the logging device (which also serves as an input terminal for the operator) is seen on the top of the console.



sites must be sufficiently synchronized to make comparison of records from two different sites possible.

▫ Software maintenance and analysis of the data logs should be performed on a separate system.

▫ The system must be expandable to handle control functions and must be able to incorporate dial-up lines to minimize future communication system costs.

▫ The system will be designed and built as if the two terminals were far apart, even though the actual distance in the prototype system is only 700 m (0.44 mi). This will make the system applicable to future HVDC transmission links.

As reported earlier (*EPRI Journal,* November 1978, p. 49), a system meeting these requirements has been developed and is now installed at the compact dc station project at the Astoria station of Consolidated Edison Co. of New York, Inc. The FDAS is expected to be a valuable support tool to the engineering team that will perform the acceptance tests of the compact dc project. The simplicity of the operator console is illustrated in Figure 1, which shows the input/output console for the remote operator position. *Project Manager: Stig Nilsson*

Semiconductors for EHV switching applications

Power-switching semiconductors, such as thyristors and transistors, have been making rapid improvement in increased voltage- and current-handling capability. So far, because of their high cost, these devices have not been applied in high-voltage switching and fault-current-limiting applications. EPRI anticipates, however, that with further improvements and cost reduction, these applications may materialize; a project just getting under way at General Electric Co. is expected to implement the change (RP1511).

Success in developing these semiconductors for circuit breaker duty will have a significant impact on breaker design because a semiconductor switch can reduce the arcing duty of an ac breaker and therefore provide faster interruption. Circuit breakers that use semiconductor switches promise to be more reliable and require less maintenance. Although EPRI is sponsoring other research on several promising fault current limiters, no low-cost or effective high-voltage ac current-limiting device is presently available. Development of such a device based on semiconductors will permit greater latitude in system expansion and should delay the need to upgrade substation equipment as fault currents increase. Lack of a dc breaker has limited dc to point-to-point transmission; availability of a dc breaker will help make dc transmission grids feasible, though not necessarily economical.

Instead of adapting existing state-of-the-art semiconductors, which are rated for continuous or repetitive duty, researchers are looking for a semiconducting device with maximum short-term (surge) voltage and current capability. Because the semiconductor will be connected in parallel with a mechanical switch, the semiconductor will only be active in the circuit when a fault is sensed. Thus the semiconductor's duty cycle may be only a few cycles, or at most, a few seconds per year.

The semiconductor will be switched in only when a fault is sensed, permitting transfer of the fault current to the semiconductor just before the mechanical switch is opened. The mechanical switch will then open and deionize, and during the same half-cycle, the semiconductor either will be switched off before the current peak or will carry current until switching off at a natural current zero. The transient voltage developed on switching the semiconductor will be limited by a parallel nonlinear resistor.

The present projects have as their goal improved semiconductor ratings to meet surge conditions. If this goal is attained, follow-on projects will integrate semiconductor strings, a mechanical switch, and nonlinear resistors into an operating switch. *Project Manager: Gilbert Addis*

OVERHEAD TRANSMISSION

Bulk-graded, filled-polymer insulators

The presence of atmospheric pollutants and moisture on insulators leads to flashover problems that result in costly outages. The nonuniform electric field common to all insulators contributes to the problem, and the problem increases in severity as the voltage and insulator length increase. Utilities attempt to prevent flashovers by periodically cleaning insulators where air pollution is known to be a problem.

One way to prevent flashover (and reduce the cost of periodic cleaning) would be to dielectrically grade the insulator. A typical post insulator has a nonuniform voltage distribution, with the electric stress concentrated at the conductor or high-voltage end of the insulator. If the electric field could be altered to selectively grade the insulator, the stress could be distributed more uniformly, and thus dielectric performance could be improved and maintenance costs reduced.

A project has been initiated with the switchgear division of General Electric Co. to determine the feasibility of achieving stress redistribution by bulk grading of filled-polymer insulators (RP1496).

The General Electric approach will be to seek out and test suitable additives that could be incorporated into a composite system of polymer resin and silica. The experimental study will focus on three types of additives: linear-resistive, nonlinear-resistive, and capacitive. In addition, resins such as cycloaliphatic epoxies and polymethyl methacrylate will be evaluated for their bonding capability. A model will be developed for determining the feasibility of combining the resistive and capacitive additives with the inert filler. Composites will be evaluated for their ability to suitably grade the stress, and samples of the best composites will be prepared. Once an optimal system is achieved, the ability of selective composites to withstand the effects of surface contamination will be evaluated by subjecting specimens to a "clean fog" contamination test.

A 16-month project has been planned, and if this concept proves economical and technically feasible, further developments and larger prototypes will be considered. *Project Manager: Bruce Bernstein*

Electrical effects of UHV lines

The study of electric and magnetic fields generated by ac overhead transmission lines has recently become a subject of major importance. With the expansion of EHV systems and the growing prospect of UHV transmission, concerns have been expressed over possible effects of electric and magnetic fields because these effects may influence line and station design. A recently completed project with General Electric has determined the nature of such effects, their impact on line design, and the methods available to control them (RP566). Some of these effects are quantifiable in terms of induced currents, voltages, and energies; others are related to long-term exposure.

A final report, EL-802, has been issued for this project and includes discussions of the following topics.

- Calculation methods and measuring techniques for transmission line fields and their effects
- Steady-state and spark discharge currents induced in people and in objects
- Methods to reduce the electric field of transmission lines at ground level
- Data on various effects of the electric field, such as people's reaction to different types of exposure, wood pole burning, and corona on grounded objects

A seminar was held on transmission line field effects during 1978 that was based on this project. Over 100 utility representatives, consultants, and contractors attended and toured the facilities of Project UHV, the site of the work on RP566. *Project Manager: Frank Young*

Wind loading research

Transmission line towers are designed to withstand the average force of the wind on conductors, with some allowance for extreme winds. Industry engineers are familiar with the formula used to calculate this force: $F = 0.00256V^2C_dA$, where V is the wind velocity, C_d is a constant that allows for air density, and A is the area. Because it is not unusual for 90% of an entire line to be made up of tangent structures (zero angle between conductor and tower), the same design may be repeated several hundred times. The added cost of allowing for even small variations in wind speed can have a dramatic impact on overall cost; for example, the addition of as little as 5 mph to a 100-mph design wind speed (5% increase) can increase the calculated wind load on conductors by more than 10%; that is, $(105)^2 - (100)^2 = 1025$, or 10.25%. Designing for even this small increase can cost several hundred thousand dollars on a multimillion-dollar line.

The purpose of a two-year project with Synergistic Technology, Inc., and GAI Consultants, Inc., is to ascertain what loads are really imposed on transmission lines by wind (RP1277). Historically, the design of transmission lines has assumed the wind to be constant across an entire span of conductor; however, because the wind often blows in gusts, this assumption appears to be conservative.

Span reduction factors (reductions in calculated wind loads on conductors) based on empirical formulas and limited test results are being used in other parts of the world. These span reduction factors range from 0.4 in the USSR to 0.55 in Europe.

RP1277 is divided into two parts: development of an analytic model and verification of the model by a field measurement program. In the development of the analytic model, a range of parameters will be taken into account. The meteorological parameters include effects of ground roughness, gust size and frequency, variation of wind velocity with height, and drag coefficients. The structural parameters include tower and conductor frequencies, conductor size, and span length.

The field measurement portion of this project will involve instrumenting a portion of an Oklahoma Gas and Electric Co. 345-kV, lattice steel transmission line with both meteorologic and structural response instrumentation. Meteorologic measurements will be made of wind velocity along the length of a conductor span and at various elevations to a height of approximately 500 m above ground. Conductor motion under these wind loads will be measured, together with loads induced in the tower. Results of this field measurement program will be compared with predictions from the analytic model. An interim report is scheduled for September 1980. *Project Manager: Phillip Landers*

UNDERGROUND TRANSMISSION

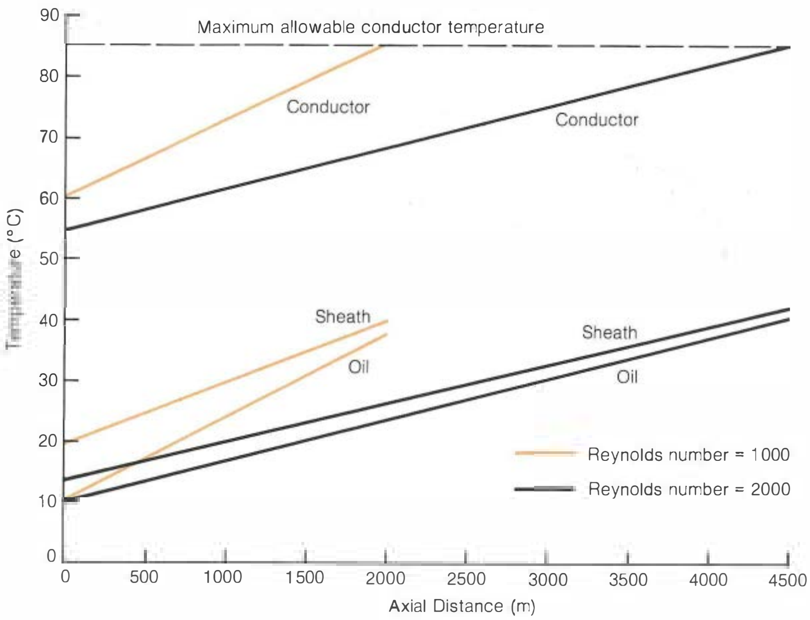
Forced convection cooling

The University of Illinois has contracted to perform basic studies involving the enhancement of thermal transfer and hydraulic flow conditions in high-pressure oil-filled (HPOF) cable systems under force-cooled operation (RP7853).

Experimental work has been completed on laboratory models (scaled-down replicas of actual circuits) to determine the flow conditions that will produce optimal cooling of the three cable phases in a pipe. Computer modeling of cable splices to determine the radial and longitudinal heat transfer in the splice has shown this region to operate cooler than the actual cable when forced-cooled. A computer analysis of the entire circuit was also developed whereby the longitudinal and radial heat profiles in the oil, sheath, and conductor can be predicted and plotted, given certain input data (Figure 2). This analysis can be applied to determine the maximum allowable distance between refrigeration units (Figure 3).

Every aspect of a cable circuit has been modeled to determine each component's effect on hydraulic pressure drop, friction, velocity, and thermal transfer of cable losses. Diffusion chambers (entrance and exit regions) have been extensively studied to determine an optimal design that will allow low pressure drop, large velocities, and small rates of oil impingement directly onto cable tables. Results from all this research, including work done on the relationship between friction factor and degree of cable snaking, will be presented in the final report, which is expected early in 1980. *Project Manager: Thomas Rodenbaugh*

Figure 2 Heat profiles for oil, sheath, and conductors. Based on a maximum conductor temperature of 85°C and earth temperature of 30°C, this plot shows two cases for a 345-kV circuit in a 12-in pipe at 180% self-cooled current rating (1505 A). The color lines are for a Reynolds number (Re) of 1000; for the black lines, Re = 2000. The maximum conductor temperature for Re = 1000 occurs at 2000 m, which would be the maximum refrigeration spacing. Note that at faster flow rates (i.e., large Reynolds numbers), sheath and oil temperatures run closer together.



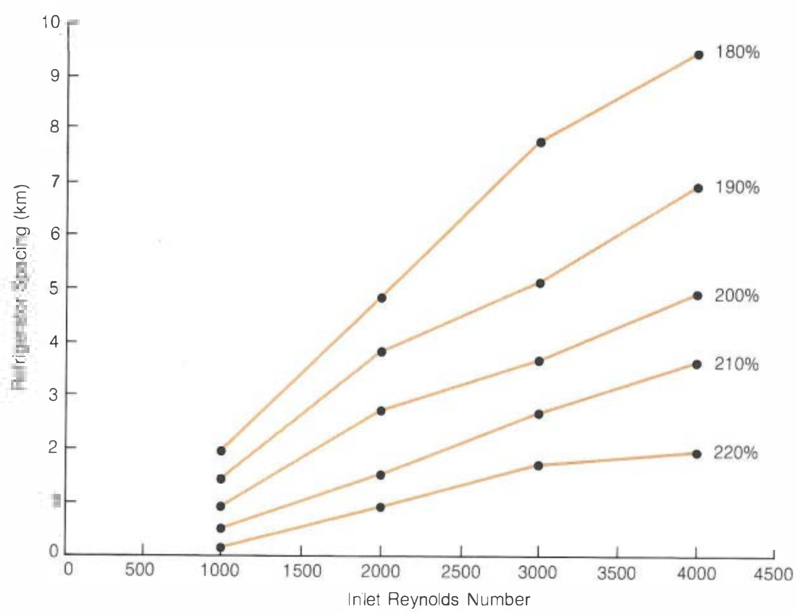


Figure 3 Based on the thermal and hydraulic performance of a 345-kV cable in a 12-in pipe, the computer was able to determine the maximum refrigeration spacing along the circuit as a function of input flow Reynolds number. Higher current ratings resulting from forced cooling are given as percentages of non-force-cooled ratings.

Electrohydrodynamic pumping

Forced-cooling of an underground HPOF cable system can increase its power-handling capacity and help maintain a realistic and safe conductor and insulation temperature. Power transfer can often be increased 80% by circulating a low-viscosity dielectric oil around the cables and extracting the heat that results from losses out of the system by refrigeration. To accomplish this, mechanical pumps must be placed periodically along the cable route to overcome viscous drag and pressure drop due to friction. Such a system requires a large inlet pressure (~4.14 kPa; 600 psi) to compensate for the hydraulic losses and to pump the fluid a meaningful distance (~1.6–2.4 m; 1–1.5 mi) at an average system pressure of 1.72 kPa (250 psi). Problems typically occur at the potheads (terminations), which are the weak link in a pressurized system, and at the mechanical pumps, which require frequent maintenance because of fatigue in the moving parts and seals.

An electrohydrodynamic (EHD) pumping electrode generates a continuous volumetric force that pumps a dielectric fluid the entire length of the electrode. This not only eliminates macroscopic pressure drop but also reduces oil inlet pressure to that of the average system pressure requirement, reducing maintenance and the need for intermittent pumps.

Under RP7871 with the University of Illinois, experimental pumping speeds of 4 cm/s have been obtained without a charge injection at voltages of 12 kV. Instead of injecting free charges into the oil to induce a pumping action from the traveling electric field, induced charges are used; these are caused by the temperature dependence of the fluid's electric conductivity when influenced by a thermal gradient. Theory predicts that a speed of 1 m/s is obtainable for the fluid tested (Sun No. 4 oil). The velocity is being optimized by correlating the effects of the position of the electrode inside the pipe, electric field strength, frequency, thermal influence, and material characteristics.

Two types of pumps have been used to improve the accuracy of the EHD theory and to investigate options and parametric tradeoffs affecting pumping velocity and efficiency.

One of these pumps consists of a segmented electrode with every third segment energized by one phase of a three-phase power supply. Because adjacent segments are 120° out of phase, one can produce the traveling electric field necessary to obtain a shear stress wave in the fluid and thus cause oil flow. The segmented pump is being used to optimize EHD theory and find the best values of voltage, frequency, phase difference, thermal gradient, and geometric position in the pipe for producing the largest flow velocities.

Because the segmented-electrode pump is about 10 cm (4 in) in diameter and is complicated to make in long lengths, another type of pump is being developed. This type uses resistively graded solid insulation around a very thin wire conductor. The periodic grading produces a net electric force or pumping action in one direction from a single-phase power source. (This is more economic than the three-phase, segmented-electrode pump.) The overall diameter is 6.35–12.7 mm (0.25–0.50 in). The concept of making a solid-dielectric pump where each segment has a different resistivity is new and lends itself more to cable application. The advantages of this pump over the segmented electrode are that it (1) needs only one electrical connection instead of 33 connections per meter, (2) uses a single-phase power supply rather than a three-phase supply, (3) is of smaller diameter, so it will fit into the cable pipe along with the three cable phases, and (4) is a less complicated structure that can be produced in long lengths (kilometers) instead of a few meters.

We believe that a practical and effective EHD pump for cooling applications can be made available if the state of the art in EHD technology is exploited. *Project Manager: Thomas Rodenbaugh*

Backfill materials

Previously reported work covered the extensive additive investigation and subsequent laboratory analyses of thermal resistivity and stability of soils (RP7841). The university of California's geotechnical engineering department is now studying durability of stabilizers in the field, particularly thermal-physiochemical changes that occur when heat load is varied. Both steady-state and transient characteristics of each of 10 trench sections are being measured, and comparisons are being made with two computer projections of heat flow and moisture profile. Analyses to date show good correlation between measured and predicted temperature and moisture profiles.

The analytic projects currently being field-validated are to be upgraded or modified in future work. The moisture flow analysis is a one-dimensional, finite difference model. Work performed under a follow-on contract will extend this model to a two-dimensional, radial profile similar to that developed for the thermal program.

A final report on Phase 2 of the project should soon be available. It is anticipated that long-term testing (approximately two years) will be part of a Phase 3 study started in October. Long-term durability and performance of additives, as well as enhanced two-dimensional computer models, are the anticipated results of Phase 3. *Project Manager: Thomas Rodenbaugh*

Cable oil study

Although they account for only a small fraction of the electrical insulating oils in use, the dielectric oils for high-voltage cables are nevertheless vital to the reliable performance of bulk power underground transmission. Cable oil is necessarily a special, highly refined fluid.

In the United States there are approximately 3000 circuit miles of underground transmission in commercial service rated 69–345 kV. The majority of these are HPOF pipe-type cables, but about one-sixth of the cables are self-contained, low-pressure, oil-filled (LPOF) cables, which are separately sheathed and installed in ducts or directly buried.

Both cable systems owe their compactness, high dielectric strength, and reliability to the unique insulation of paper tapes impregnated and filled with dielectric oils, in a wide range of viscosities and special characteristics required by the different cable systems. For example, in HPOF pipe-type cables, the impregnating oil must have a high viscosity (3600 Saybolt seconds universal [SSU] measured at 100°F [38°C]) to achieve maximum impregnation without loss during shipment and installation, whereas the viscosity of the pipe filling oil selected may be as low as 50 SSU, depending on the particular HPOF application.

At present, most utilities follow the practice of purchasing cables and components, pipe, and filling oils separately and obtain pipe-filling and make-up oils directly from oil suppliers. Utilities have stated a need to supplement existing ASTM specifications and to obtain better assurance of suitability, compatibility, and availability for the various oils, as well as to obtain more suitable functional tests. These functional tests would better guide the utilities and industry in the selection, control, and qualification of cable filling oils for reliable service. With the growing scarcity of traditional petrochemicals, functional tests would also be helpful in evaluating new fluids.

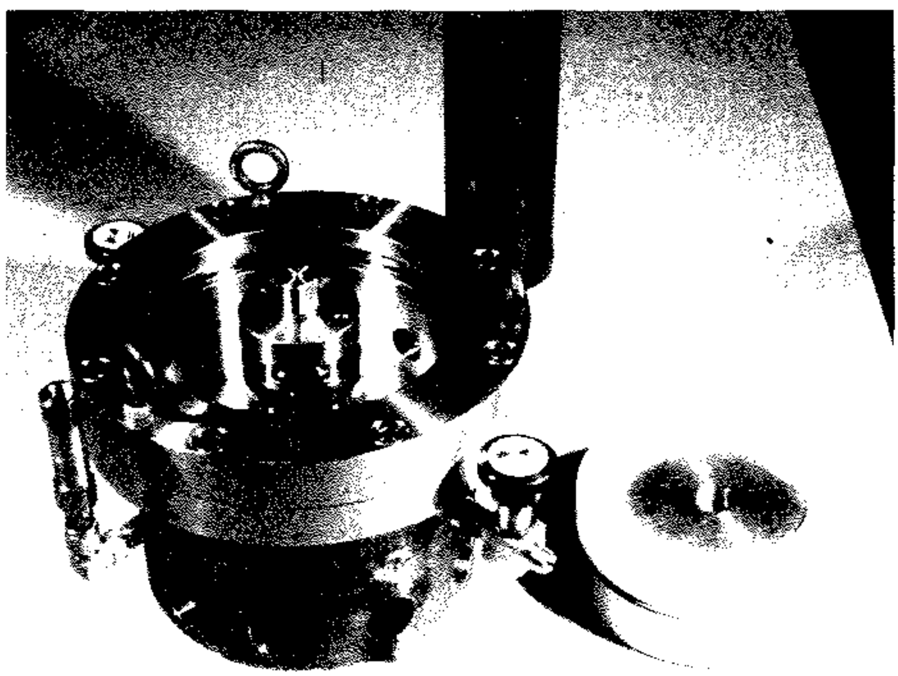


Figure 4 Six combinations of cable-impregnating and cable-filling oils are under test in 50 of these flat-cell models, which are equipped for pressure, voltage, and power factor measurement. The cells can be maintained at temperatures as high as 160°C and voltage stresses up to 600 V/mil for as long as 88 days.

In response to these needs, EPRI has contracted with General Electric for a 30-month study of insulating and filling oils for paper-insulated, oil-impregnated cables (RP7872). Functional test methods, test equipment, and procedures are being developed to complement existing specifications.

The test method is based on the simulated life-testing of the paper-oil insulation components, first by determining the thermal degradation (aging) processes of the paper-oil systems as a function of time (rate) and temperature (activation energy). Next, the degradation effects of applied voltage stress on paper and oil will be studied under conditions of constant time and temperature. The third step would establish the interrelated effects of time, voltage stress, and temperature. From the studies and procedures, increased understanding of the complex aging phenomena of paper-oil systems will be gained, and better definition of and criteria for acceptable durability will be evolved. A reference base (established with combinations of known insulating oils) will be provided for comparative evaluation and qualification for new fluids.

In an operating cable, the paper-oil insulation is expected to maintain dependable mechanical, electric, and dielectric stability over a 40-year life. An effective functional test to evaluate the oil component must establish the ability and compatibility of the paper and oil under simulated operating conditions and then accelerate the aging process.

At present, six combinations of cable impregnating and filling oils of known characteristics are under test in a series of 50 flat-cell models equipped for pressure, voltage, and power factor measurement (Figure 4). The cells can be maintained at temperatures as high as 160°C (320°F) and voltage stresses up to 600 V/mil for as long as 88 days. Under accelerated aging, the cellulose paper is maintained under electrical stress between the cell electrodes and comprises nine die-cut sheets of cable paper with longitudinal slits (simulating butt gaps) in four alternate sheets.

The effects of aging will be determined by power factor measurements, physical and chemical measurements on the paper, analysis of the oils, and analysis of the contamination and decomposition products by liquid and gas chromatography. The relative performance of oils will be determined from these aging tests and from analysis of the paper-oil kinetics under both temperature and electrical stresses. *Project Manager: Stephen Kozak*

DISTRIBUTION

Destructive failure of distribution transformers

The typical distribution transformer used by the utility industry is so constructed that insulating oil is a vital part of the design. The oil serves as a coolant by carrying heat away from the core and windings to an external cooling medium in addition to performing its usual function as an electrical insulating medium. Transformer oil, however, can aggravate problems that originate elsewhere in transformers. Arcing can occur in the oil, initiated by an internal fault or the operation of a primary fuse immersed in the oil. The dissociation of the oil in the area of the arc produces hydrogen gas at high pressures. The resulting shock wave, hydraulically transmitted throughout the transformer, may blow off the transformer cover, blow out any mounted bushings, or rupture the tank. Burning oil is sometimes ejected. Such destructive failures of pole- and pad-mounted transformers can result in property damage, personal injury, and environmental contamination.

Manufacturers and utilities have endeavored to eliminate or minimize this problem by various measures, including use of stronger tanks, pressure relief valves, external fusing, and current-limiting fuses. These measures have, in part, minimized the problem, but no solution found to date has been fully satisfactory both technically and economically. A more revolutionary approach is required to eliminate destructive failures of distribution transformers. One such approach eliminates the need for oil in the transformer, which involves fundamental changes in transformer design.

The McGraw-Edison Co., with the sponsorship of EPRI, is presently developing a distribution voltage class transformer that will not be subject to destructive failures (RP1143). The University of Illinois and the University of Missouri are working with McGraw-Edison on this three-year project. The development is based on the use of new inorganic insulating materials, in conjunction with an advanced insulation application and coil-winding technology. This approach precludes the use of transformer oil in any design area, thus removing the basic cause of destructive failures in the transformer. Because the oil insulant is replaced with inorganics, a significant increase in the operating temperature range of the transformer is allowed. The higher tolerance for overload temperatures will permit greater current densities in conductors, resulting in smaller core and coil assemblies and a decrease in insulation volume.

Several full-size, 15-kV class, 50-kVA prototype transformers, both pole- and pad-mounted, will be fabricated and technically evaluated. A complete study of projected manufacturing costs of the designs under development will also be performed. *Project Manager: Robert J. Stanger*

Wood preservatives for new poles

Almost all new utility poles are treated full-length for maximum service life. Eventually, all poles in service are subjected to a costly maintenance program that involves regular inspection. Results of the inspections may dictate removal, retreatment in place, or deferral of action until the next inspection.

For initial treatments, the most commonly used preservatives are a solution of pentachlorophenol in petroleum oil (penta) and either creosote or creosote–coal tar. Penta treatment has been gradually superseding creosote because it gives comparable decay protection, presents a more uniform and pleasing appearance, and is less susceptible to bleeding. Water-borne salt treatments, such as ammoniacal copper arsenate and chromated copper arsenate, appear to be about as effective as penta and creosote; however, they are used infrequently for pole treatment because they cause the poles to be more conductive and the treatment cost is higher (the poles need to be more thoroughly seasoned before treatment).

Based on laboratory and field tests, it has been estimated that wood that is sufficiently treated with penta or creosote should be able to resist decay for 30–50 years. But utilities have been unable to realize this level of performance for a variety of reasons. For example, it is difficult to achieve sufficient penetration and retention to prevent decay organisms from getting into untreated or inadequately treated interior wood. Douglas fir, a western pole wood, is particularly vulnerable to this because its sapwood is thin and its heartwood is very resistant to treatment penetration. Seasoning checks that develop after treatment can open up paths through the treated wood to the untreated interior.

A number of techniques are being used to overcome this problem. Drying the poles at elevated temperatures develops internal checks that limit the depth of posttreatment surface checks but reduces the strength of the wood. Deep mechanical incising facilitates penetration of the preservatives. Deep kerfing in the ground line area before treatment aids treatment penetration and prevents subsequent checking in this area. Holes drilled entirely through the poles at the ground line allow better preservative penetration in this area, but reduce pole strength. None of these techniques appears to be an optimal solution to the internal decay problem.

EPRI, therefore, has initiated a study with Michigan Technological University's Institute of Wood Research to develop improved treatment processes and materials for new poles (RP1528). Two specific objectives are set for this 5-year effort: to develop a better understanding of the fundamental chemical and biological processes of wood deterioration; to investigate and develop new or improved cost-effective pole treatment materials and/or processes that will prevent decay of all poles in severe environments for at least 40 years. The understanding developed in the first objective should reveal promising new departures from the fungicidal wood impregnation presently practiced. These new concepts, in addition to efforts to improve existing practices, will be investigated to achieve a more effective pole treatment process. *Project Manager: Robert Tackaberry*

Tree growth control

The cost of clearing trees from electric distribution lines is a major portion of a utility's distribution maintenance budget. The expenditure is repetitive and nonproductive. EPRI's research on reducing costs includes two projects to develop cost-effective methods to minimize sprout regrowth after trimming; both projects should extend the interval between trimmings and thus reduce annual trimming costs (RP214, RP380).

Encouraged by the results of these two projects, EPRI has extended both to expand field trials. Foresters at cooperating utilities in different regions of the country will be instructed by the principal investigators on application methods and evaluation of the results. Data from these additional applications will add to our knowledge of each system's effectiveness over a wide variety of tree species.

In the first project (RP214), a method was developed for injecting small volumes of concentrated aqueous chemical solutions into trees for sprout regrowth control. A lightweight, portable, air-powered injector system was developed and used effectively during the last three years of this five-year project. A screening procedure was applied to greenhouse seedlings to test the effectiveness of numerous chemicals in controlling regrowth on 23 tree species. Two chemicals were selected that (when administered in appropriate concentrations) controlled sprout regrowth without causing unacceptable symptoms of phytotoxicity. An initial cost analysis by the investigator and utility cooperators showed that a 30–50% reduction in annual tree-trimming costs may be obtainable with the adoption of this procedure. A final report on the first five years' work is available (EL-1112).

A bark-banding method for application of growth-inhibiting chemicals to tree trunks was investigated in RP380. After extensive screening, chlorfluorenol methyl esters in a vehicle of diesel oil and toluene was found to control tree growth in a wide variety of species. A report on this three-year project will be available soon. *Project Manager: Robert Tackaberry*

Electronic watthour meter

The present single-phase induction watthour meter (IWM) used for energy measurement and storage is a very reliable, long-life, accurate, low-cost device with a moderate level of security. It operates accurately over a wide range of temperatures and other environmental conditions.

However, the IWM has several disadvantages. By the nature of its analog register operation, it is an inflexible device that cannot be easily used for distribution automation functions, such as time-of-use metering, load control, or multiregister data storage. Furthermore, the IWM has a limited bandwidth and hence does not accurately measure power in thyristor-controlled loads, such as dimmer switches on lights and other loads that cause the current to have a nonsinusoidal waveform. Such error, if any, would be in favor of the customers.

EPRI has a research project under way to develop a fully electronic watthour meter (EWM) that has the physical and environmental reliability of the IWM plus the accuracy and improved bandwidth to measure power in all loads (RP1420). The EWM will be capable of performing three types of distribution automation functions.

- Measurement of voltage and current by electronic means to an accuracy acceptable to utilities
- Computation and storage of kilowatthour and peak demand data for these time-of-use periods
- Provision of programmable logic for control of three loads and switching of three time-of-day registers

The objective is to develop an EWM that has no moving parts. The customer should be able to read the data registers with a digital readout, and the meter reader could then use either the digital readout or an electronic readout directly from the registers. Such data could be stored in a digital format readily accessible for remote meter reading by any bidirectional distribution communication system. The instrument will ultimately be a sealed package that will greatly minimize the possibility of tampering and will include disconnect indicators. Another objective is to provide an instrument for a cost below that for existing meters and still provide the same functions.

EPRI has selected McGraw-Edison and Texas Instruments Corp. as the project team. McGraw-Edison will develop the overall system design, subsystem integration, data storage, digital and electronic data readout, and packaging. Texas Instruments will develop the voltage and current sensors and combine them with an integrator for measuring energy and power, all in integrated circuitry.

If the prototype design meets EPRI requirements for performance and cost, 100 prototype units will be manufactured for field demonstration on cooperating utility systems. A one-year field test of the EWMs will include evaluation of accuracy, reliability, maintenance, and performance of the meters. *Project Manager: William E. Blair*

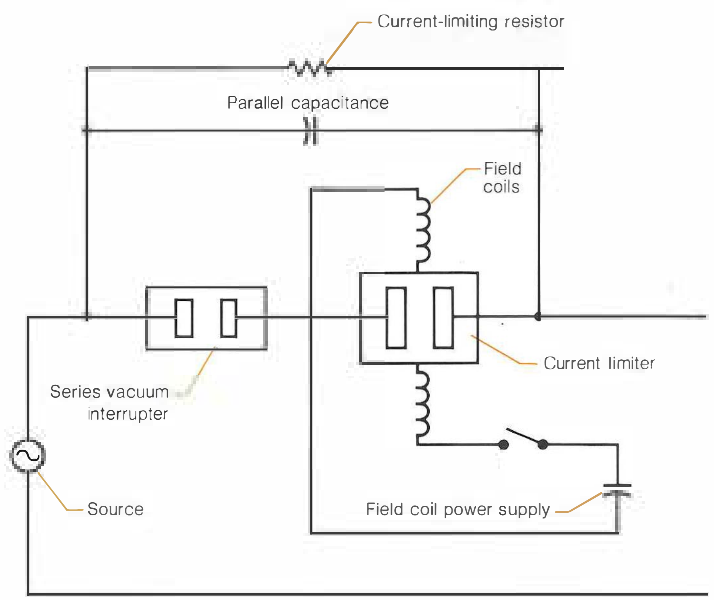
AC SUBSTATIONS

Vacuum arc fault current limiter

Development of a device to limit the magnitude of fault current during short circuits has been the goal of utility engineers for some time. Such a device would permit utilities to postpone or eliminate the need to replace equipment that can no longer handle increased fault current resulting from system growth. It would also permit reduction of fault current withstand requirements of new equipment and thereby improve cost and reliability.

A project (RP564) with Westinghouse Electric Corp. focuses on developing a fault current limiter that uses a vacuum arc for current commutation (Figure 5). The electrodes of a vacuum device are rapidly separated during the rise of the fault current. When the electrode gap reaches several centimeters, a magnetic field is applied transverse to the arc path. This field causes arc instability with a resultant rapid rise in the arc voltage. In the presence of a parallel capacitor, the current is then diverted from the vacuum device into the parallel capac-

Figure 5 Single-phase representation of the vacuum arc current limiter. The current limiter diverts fault current into the parallel capacitance and ultimately into the parallel resistor. A series vacuum interrupter aids the current limiter in withstanding the ensuing recovery voltage.



itor. When the vacuum arc extinguishes, the current continues to flow into the capacitor and ultimately through the parallel, current-limiting resistor. A conventional vacuum interrupter is connected in series and is operated simultaneously with the vacuum fault current limiter in order to aid in withstanding the recovery voltage that occurs as a result of the resistive voltage drop.

Results have shown that it is feasible to limit the instantaneous value of the fault current to less than the symmetric peak in a 72-kV system that has 10–15 kA (rms) available. Further research is directed toward increasing this current level and reducing the amount of parallel capacitance to less than 50 μF. Later this year a cost-effective conceptual design will be developed for a 145-kV device to assess the practicality of applying this principle. *Project Manager: Joseph Porter*

Dispatch operator training

The EPRI hybrid power system simulator was completed in 1975 by the University of Missouri–Columbia to support engineering studies of long-term dynamic behavior for power systems (RP908-1). The capabilities of this hybrid simulator were later extended to include short-term dynamics, protective relaying, and automatic parameter setting (RP908-2). The power system simulation capabilities of the EPRI hybrid are described in *Improvement and Performance Evaluation of an Advanced Hybrid Simulator for Power System Dynamics* (EL-724).

Researchers at UM–C are now adding man-machine interface equipment and software to the hybrid so its potential as a training tool for dispatch operators can be evaluated. Figure 6 illustrates the basic hybrid computer from RP908-1 that has been used for systems engineering studies of the power system. Recent engineering studies supported by EPRI and the utility industry were concerned with the impact of batteries at substations and the effect of tie-line bias settings on generation control.

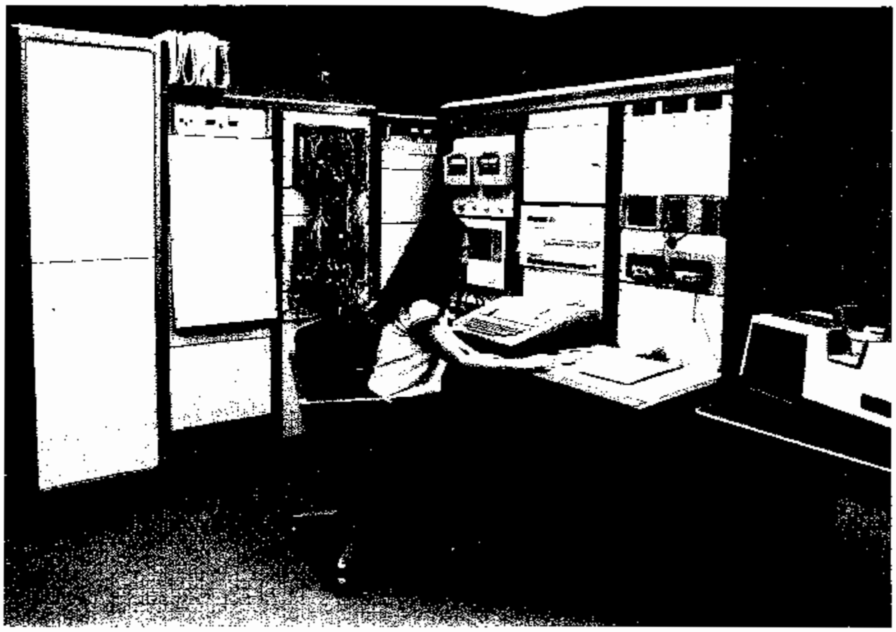
Figure 7 shows equipment typical of that used by power system dispatch operators in modern dispatch centers. With this equipment and the corresponding support software, various stress conditions on the power system can be realistically presented to a dispatch operator. Three strip-chart recorders will present total generation, net interchange, and system frequency, respectively. The printer will be used during training as an alarm logger. All other power system information will be presented via two color cathode ray tubes (CRTs). The CRTs can be used for one-line diagrams and tabular displays. The dispatch operator will be able to interact with the simulated system by using a light pen with each CRT or by using a keyboard.

The objectives of this current research are to gain experience with simulator response requirements and training-case development techniques. Any simulator must model the operation of the power system being simulated. The real power system network operates at 60 Hz; therefore, network power flows adjust to changes in generation or to switching operations in less than a second. The real power system instrumentation and data acquisition equipment brings data into the dispatch center every 2–6 s. The dispatch center computer system processes the acquired data and updates information being displayed. The dispatch operator, therefore, sees the effect of power flow changes 4–8 s after an actual change takes place.

If realistic training is to be achieved, the response of a training simulator must be reasonably close to the response the dispatcher would observe if he were at his console, viewing information from the real power system. The speed of the hybrid simulator will allow researchers to vary the response rate of the simulated system. The analog portion of the hybrid operates at 1200 Hz; therefore, a power flow for the daily load pickup that normally takes 2 h could be presented to a trainee in 6 min. Toward the other extreme, the response of the interface to the simulated power system can be slowed until the quality of operator training is compromised. The variable response capability of the hybrid simulator will allow researchers to evaluate the effect that simulator response has on training. Both the realism of the training interface and a speedup of normal events can be evaluated.

The second objective of this research, techniques for developing training scenarios, will be addressed once the set of normal and emergency operations training cases is checked out. A procedure for specifying a training scenario was established, and the specifications were reviewed by utility personnel before actual coding was begun. The display formats and the time line of simulated events will be defined to support the desired scenario. A computer card image format has been defined to specify the scenario event time line. A data file of card images on disk will be used to control the actual scenario. Operating personnel

Figure 6 The EPRI hybrid computer was developed to support engineering studies of power system dynamic behavior.



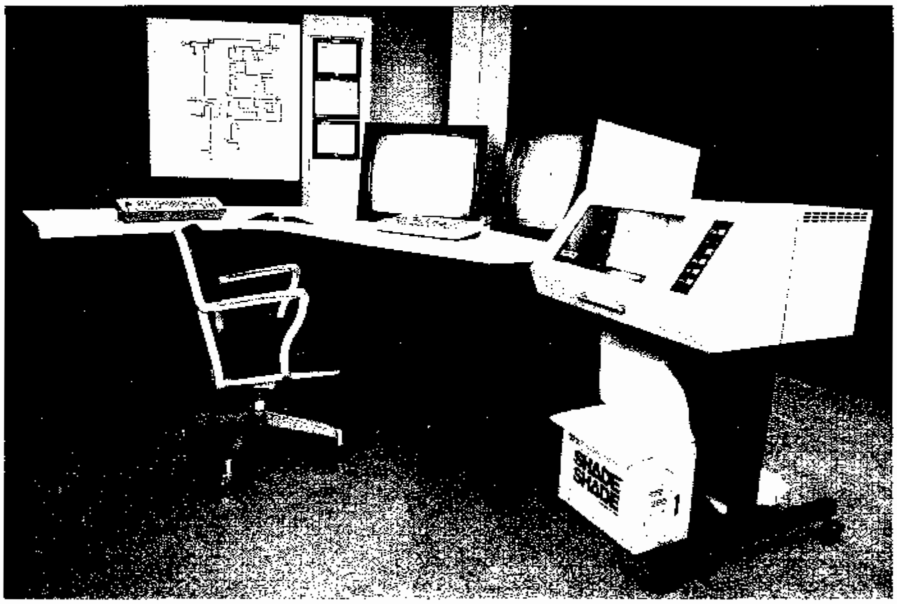


Figure 7 Dispatch operator console equipment that is being added to the EPRI hybrid computer. The combination will be evaluated as a dispatch operator training tool.

familiar with the system being simulated will participate in the evaluation of the training scenarios. The acceptability of each training scenario and the effort required to produce it will then be evaluated.

If the use of the hybrid computer as a dispatch operator training tool is acceptable, UM–C intends to offer training courses to electric utility personnel. Between training courses, the hybrid (with the operator interface) can be used by other EPRI researchers to evaluate various advanced concepts for use of CRTs and other man-machine interface devices. *Project Manager: Donald Koenig*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

ENERGY-ECONOMY INTERACTION MODELS

What are the economic impacts of uncertainties in the energy sector, such as possible restrictions on new electricity-generating capacity, increases in the cost of generating capacity, and increases in world oil prices? What is the value of having a new energy technology, such as the breeder reactor, available for large-scale commercial use in 2000 instead of 2020? An understanding of the issues surrounding such questions is needed to guide the planning of R&D expenditures and to better inform those involved in the public policy debate on energy. Because an essential ingredient in the analysis of these questions is the interaction of the energy sector with the rest of the economy, the Systems Program has sponsored studies of energy-economy interactions since it was founded.

Energy-economy models forecast energy and economic phenomena on the basis of general assumptions about the future. The analyst specifies the assumptions, and the model shows the implications of these assumptions according to its own structure and behavioral assumptions. Because the relationships within and between the economy and the energy sector are very complex, models are set up as computer programs designed to keep track of the assumptions and behavioral relationships.

All energy-economy models forecast GNP and consumption; detailed models can forecast output by industry and changes in industrial composition. Energy sector variables forecasted typically include total energy use, the prices of some forms of energy, and the use of different energy technologies.

The principal economywide assumptions that must be specified in these models describe growth rates for productivity and labor force. The principal energy sector assumptions include supply curves for different energy forms and the costs and characteristics of technologies that transform energy from one form to another. In addition to assumptions about the economy and about the energy sector, assumptions are made about the strength and nature of energy-economy interactions. It is this link that is the distinguishing feature of energy-economy models. The principal information flows in energy-economy modeling systems are shown in Figure 1.

Energy-economy models differ in the time periods of their forecasts and in the types of analyses for which they are best suited. Models concentrating on the near future tend to have greater economywide detail and are more oriented toward analyzing the effects of energy policy, while models concentrating on the more distant future tend to have greater energy sector detail and are more oriented toward assessing the effects of new technologies, including the effects of energy R&D expenditures.

When using models of energy-economy interactions, it is important to understand their limitations.

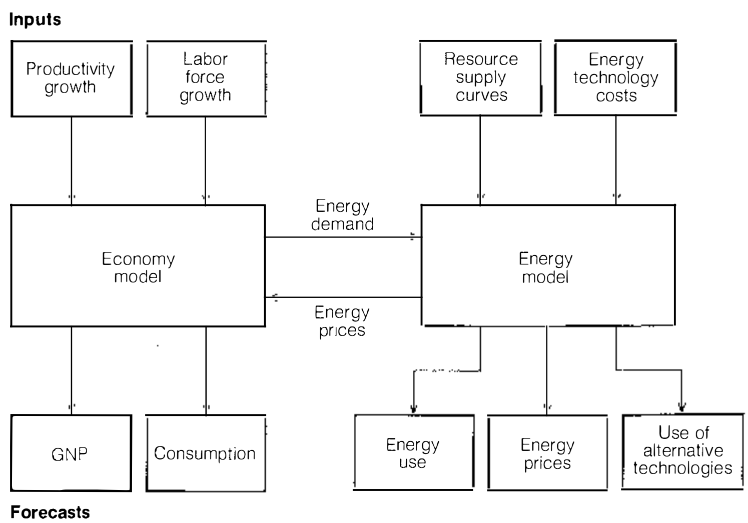


Figure 1 Information flows in energy-economy modeling systems.

▫ These models focus on the intermediate and long terms and, in general, cannot be used to analyze the effects of the energy sector on the economy in the very short run, when the vagaries of monetary and fiscal policy dominate.

▫ Because most energy-economy models assume equilibrium in the labor market, they cannot be used to predict long-term changes in unemployment. Instead, changes in the level of economy activity caused by energy phenomena translate into changes in the real wage.

▫ Energy-economy models generally do not have financial or monetary sectors, so they cannot be used to predict energy sector effects on inflation in the long run. However, they can predict changes in relative prices as a result of changes in the energy sector.

The principal influence of the economy on the energy sector is the effect that the level of economic activity has on the demand for energy by producers and the household sector. Another link is the cost of inputs provided by the economy to produce energy.

As reflected in these models, there are three ways the energy sector influences the economy. First, if there is an adverse change in energy supply, more economic resources (principally capital and labor) must be directed to providing a given amount of energy. Because the total resources available are limited, smaller amounts are then available to produce other goods and services.

Second, the higher resource cost of producing energy is reflected in higher prices for energy. Producers trying to minimize the costs of production will substitute other factors for energy. When more nonenergy inputs are used in energy production, fewer are available to produce goods and services, and once again the capacity to produce is diminished. The size of this effect depends on how easily other inputs can be substituted for energy. The parameter describing the ease of substitution is called the elasticity of substitution and is the focus of considerable research.

Third, adverse changes in the energy sector reduce output, which reduces not only current consumption but also investment. Since investment is the mechanism by which the capital stock grows, higher energy prices cause reductions in future as well as present consumption.

In a recent study the Hudson-Jorgenson long-term interindustry transactions model (LITM) was used to investigate the implications on the national economy of energy sector uncertainties directly affecting the utility industry (RP1152). For this analysis LITM was linked to the Baughman-Joskow regionalized electricity model (REM). The combined modeling system was exercised over a set of scenarios designed to show the interactions among the uncertainties.

LITM consists of two interdependent elements, a macroeconomic growth model that determines the general pattern of economic growth and an interindustry economic model that provides sectoral detail, with emphasis on the energy sector. The model, which forecasts economic growth and the structure of the economy to the year 2000, has been used in numerous studies, including the first Energy Model Forum (RP875), the Ford Foundation's Energy Policy Project, and the Edison Electric Institute's study *Economic Growth in the Future*.

The Baughman-Joskow electric utility model, which represents the electric power sector in much greater detail than LITM, simulates the demand for electricity, the production of electricity, the expansion and financing decisions of utilities, and the regulatory process for the nine U.S. census regions to the year 2000. In the combined modeling system, LITM provides REM with estimates of electricity demand and fuel prices and REM provides LITM with the price of electricity, the quantities of fuels consumed in electric power generation, and utility investment requirements.

The combined modeling system was operated to show the economic implications of three sets of uncertainties: whether there would be a moratorium beginning in 1978 on the construction of new nuclear plants; whether the environmental costs associated with coal plants would be high or low and whether coal and oil prices would rise significantly from 1978 levels; and whether the growth rate of coal-burning plants would be unrestricted or whether it would be significantly reduced by environmental pressures. Because the study assumed that each of the three uncertainties could take one of two values, there were eight possible cases, presented as scenarios 1 through 8 in Figure 2. Scenario 8, the least constrained case, is used as a basis of reference in discussing the implications of the uncertainties.

The combined modeling system was exercised to compute the implications of each scenario; the results are presented in Table 1. They show that the uncertainties examined can have large annual impacts on the absolute level of GNP. The circumstances leading to scenario 1, for example, would have a cumulative effect on GNP from

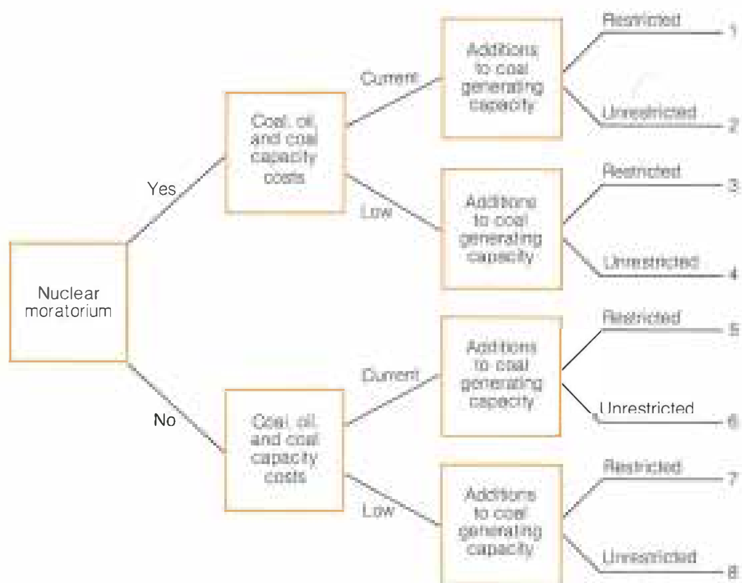


Figure 2 Eight energy-economy scenarios, defined by uncertainties in three areas.

Table 1
YEAR 2000 COMPARISON OF SCENARIO RESULTS WITH THE BASE CASE

Scenario*	Decrease in GNP ($ × 10⁹)**	Decrease in GNP (%)	Increase in Price of Electricity (mills)**	Increase in Price of Electricity (%)	Decrease in Electricity Generation (10^{12} kWh)	Decrease in Electricity Generation (%)	Decrease in Primary Energy (10^{15} Btu)	Decrease in Primary Energy (%)	Increase/Decrease in Imports of Oil and Gas (10^{15} Btu)	Increase/Decrease in Imports of Oil and Gas (%)
1	225	5.4	41	33	1.8	28	30	22	3.7	10
2	204	4.9	35	28	1.6	25	30	22	−6.3	16
3	55	1.3	27	22	1.1	17	10	7	21.5	56
4	49	1.2	14	11	0.6	9	9	6	1.4	3
5	152	3.7	21	17	0.9	14	21	15	−9.4	24
6	147	3.6	20	16	0.9	14	21	15	−9.4	24
7	6	0.2	5	4	0.3	5	1	1	1.2	3

*Scenarios are described in Figure 2. Scenario 8 is the base case against which the other scenarios are compared.
**All monetary amounts are based on 1978 dollars.

1978 to 2000 equivalent to approximately $10,000 (in 1978 dollars) for every person in the country, or $225 billion. This estimate is a best guess but is uncertain because the economic impact is sensitive to assumptions about the economy's flexibility in substituting other inputs for energy. If the economy was assumed to be less flexible, the economic impact would be even greater; if it was assumed to be more flexible, the impact would be smaller. The percentage changes in GNP are not as dramatic as the absolute costs because the underlying trends in economic growth that were assumed in this analysis approximately doubled the GNP by 2000. The percentage impacts are still not small; in scenarios 1 and 2 they approximate the percentage of GNP spent on national defense in 1978.

Table 1 also presents the implications of the scenarios for the utility and energy sectors: the effects on the price of electricity and total generation in the utility sector and the effects on the total demand for energy and for oil and gas imports in the energy sector. All the variations on the reference case cause the price of electricity to rise, generally by a large percentage. When combined with the model's assumptions about the elasticity of demand, these price increases reduce the total generation of electricity. The reductions in total energy use in the different scenarios were because of the effect of higher prices on demand.

Oil and gas imports are greatly affected by price, but they are also sensitive to assumptions that simultaneously limit the expansion of coal and nuclear plants. Scenarios 1 and 3, in which both coal and nuclear capacities are limited, oil- and gas-burning plants, including peaking units, must operate at high utilization rates to prevent shortages of electricity. Hence, there is a need for much more oil and gas.

This modeling system is being used to investigate the implications of portions of the president's energy message of July 15. Still other runs are planned to examine the implications of higher oil prices and quotas on imports. *Project Manager: Victor Niemeyer*

RESIDENTIAL HVAC ENERGY REQUIREMENTS

The technical performance and measurement subprogram is sponsoring several projects that involve load research and engineering modeling of residential heating, ventilation, and air conditioning (HVAC). This research should eventually make it possible to generalize load research data (so that data gathered in one service territory could be used in another) and to evaluate the load impacts of conservation measures and HVAC equipment choices through the use of verified engineering models.

Modeling building loads and system performance

Historically, engineers have sized residential HVAC equipment by using steady-state flow equations to determine the design heating and cooling loads for the structure. However, these steady-state design equations are not satisfactory for determining the actual time-dependent fuel requirements because the design temperatures seldom occur and because structures and HVAC systems have time-related responses. While there are practical methods of proportioning the design load to obtain approximate monthly, daily, and hourly loads, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and others have recognized the need for more accurate methods of determining the hourly and seasonal energy requirements of residential structures.

Attempts to develop such methods immediately encounter the dilemma of how to separate the effects of weather, occupancy, and the physical structure itself. Furnaces behave differently out of the laboratory; houses interact with their heating systems; and the habits of occupants have a huge effect—hence, the need to incorporate a load research outlook.

The first major demand and conservation project in this area was conducted by Ohio State University (RP137). The project involved field measurements in both occupied and unoccupied (control) houses and the development of a highly detailed engineering model (EA-894). The model was based on a consideration of the best techniques available and incorporated the response factor technique for simulating heat loss through multilayered building envelope elements, a dynamic approach to simulating

HVAC equipment performance, and simulation of variable (floating) indoor temperatures (*EPRI Journal,* July/August 1978, p. 58).

EPRI has contracted with Battelle, Columbus Laboratories to extend the OSU work in several important ways (RP1364). The full engineering model is being updated, with a new evaluation of air infiltration submodels and several changes to decrease the code's computer-running time. One key aspect of this task will be the reorganization of the input structure and full documentation to make the model accessible to any sophisticated user.

RP137 originally included two sets of field tests—the highly detailed measurements from houses in Columbus, Ohio, and less detailed remote-site measurements from eight houses in each of six other cities across the country. In RP1364, Battelle is using the latter data to further validate the model's accuracy for different climates and structures. The fully validated model would be versatile and readily usable for an extensive comparative study of the performance of alternative heating systems based on typical houses in various degree-day zones. This work will result in load profiles and performance analyses for different HVAC alternatives.

One of the original intentions of this work will bear fruit in the final part of RP1364. The degree-day formula, even as modified in various ways, is not adequate to provide accurate estimates of energy use by HVAC systems. Reducing the full model to a simpler calculative procedure will make possible accurate predictions of seasonal energy use and peak loads. This simplification will be done (1) by deleting parts of the calculation that are important to the hourly results but do not have much effect on the seasonal results, or (2) by leaving the model intact but providing simplified input and output structures, or (3) by developing "empirical" curves and equations based on output from the full model. This last choice is currently favored because it would provide a neat replacement for the ASHRAE degree-day-type formula and would be derived from a detailed, fully validated engineering analysis.

Impact of heat pumps on utility system loads

EPRI and the Association of Edison Illuminating Companies (AEIC) sponsored a study to monitor the performance of 120 heat pumps installed in single-family residences (RP432). The contractor, Westinghouse Electric Corp., collected data on weather variables and on the electrical loads of the compressor, the fan, and the total HVAC system (including resistance backup), as well as the total electrical load for the house (EA-793). The data were recorded at 15-min intervals for two heating seasons and one cooling season. On alternate days, 43 of the houses used resistance heating only so that the building heat requirement (as distinct from the energy supplied to the HVAC equipment) could be measured. In this way, Westinghouse was able to measure the change in load attributable to heat pump operation as compared with electric resistance heating (*EPRI Journal,* July/August 1978, p. 59).

Gordian Associates Inc. is completing a follow-on study that uses the Westinghouse data to model the impact on utility loads that would result from widespread conversion to heat pumps (RP1100). The project has had several phases. A model similar to the OSU building load model was calibrated against the resistance-heating-only data. Then a detailed heat pump simulation model was used to reproduce the heat pump data. As in the work described above, the validation of these models involves several nontrivial steps. The first model requires climatic data, such as outdoor temperature and solar radiation as a function of time, and a detailed architectural description of the house. The internal heat gains resulting from appliance and lighting use depend on occupancy

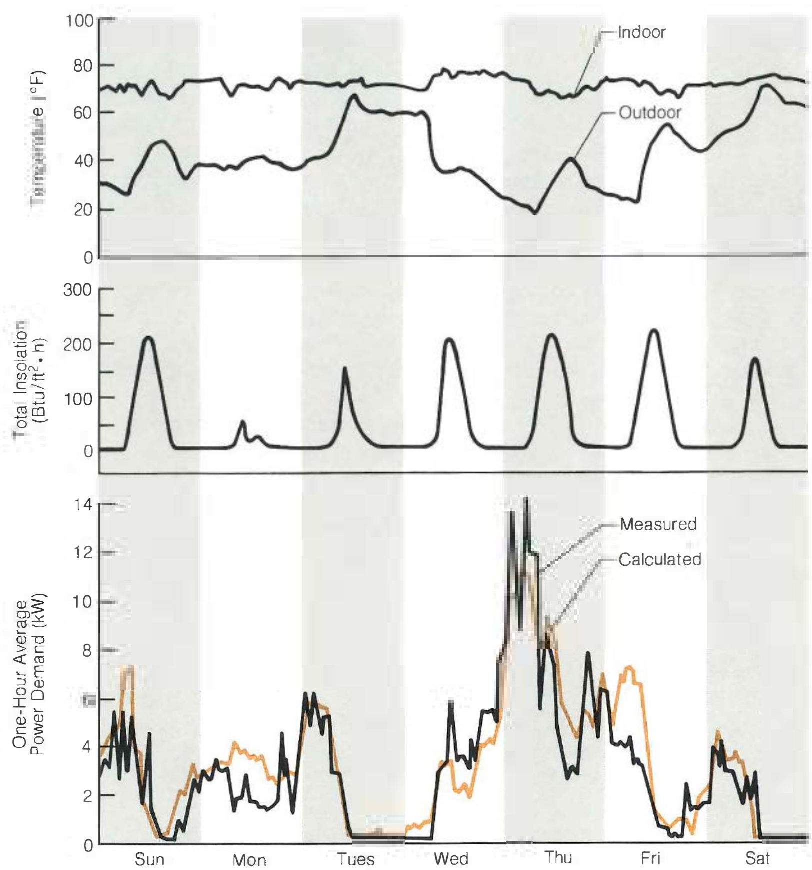


Figure 3 The measured and calculated heating electricity demand (kWh/h) is shown for a typical week, together with the measured insolation and indoor and outdoor temperatures. The model is able to simulate the hourly load trends even over the wide range of conditions. Shading indicates days when only resistance heating was used.

schedules and were approximated by subtracting the HVAC load from the total house load. Precise heat pump load curves had to be obtained from the manufacturer. Some results are shown in Figure 3.

An additional level of analysis is needed to generalize individual house load results into a form that could predict an impact on a utility system load. Since individual loads do not occur at the same time, the relationship between individual peaks and group or system peaks is not easy to discern.

Gordian has tried a number of approaches for modeling group loads. One involves direct regression analysis on field data. In another, a typical house is simulated in detail and the results are then "smeared" according to previously determined probability distributions. The most ambitious approach offers the best analogy to the real world. A Monte Carlo technique is used to create a sample set of houses, and each house is simulated in a simplified version of the load model. The results are then added together, just as real loads add together. The final result will be a simulation of the overall impact on a utility system, given the level of market penetration by heat pumps and data describing the demographic and load characteristics of the service territory.

Water heaters

In another project cosponsored by AEIC, Gilbert Associates, Inc., is using an experimental design very similar to that of the heat pump field tests to monitor 120 electric water heaters in order to estimate their load impact and determine the transferability of data from one service territory to another (RP1101). An attempt will be made to account for the hot water draw schedule (which is also being measured) with a behavioral model based on customer demographics. An engineering model of the water heater should then be able to simulate the resulting electrical load. *Project Manager: Edward Beardsworth*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP364-2	Combustion Processes in a Pulverized-Coal Combustor	21 months	224.2	Brigham Young University *J. Dimmer*
RP422-5	Dry-Cooling Tower Demonstration	6 years	--	Pacific Gas and Electric Co. *J. Bartz*
RP832-3	Coal to Methanol: Engineering Evaluation of Commercially Proven Technologies	5 months	261.3	D M International Inc. *N. Herskovits*
RP1086-6	Development of Electrolytic Hydrogen Generator System	13 months	210.0	Teledyne Energy Systems *B. Mehta*
RP1136-5	Energy Conservation and Load Management Potential of Electric Vehicles, Phase 1—Electric Vehicle Demonstration	2 years	559.5	Tennessee Valley Authority *R. Ferraro*
RP1201-11	Evaluation of Voltage Transient Suppression Devices for Saving Electric Energy	4 months	40.3	Alexander Kusko, Inc. *R. Ferraro*
RP1258-1	Absorption Steam-Stripping Pilot Plant	32 months	2837.8	Tennessee Valley Authority *S. Dalton*
RP1261-3	Application of Sulfur Dioxide and Iron Ferrate as Biocides in Electric Generating Plant Cooling Systems	9 months	47.8	University of Miami *W. Chow*
RP1266-10	Corrosion and Deposits: Abstracts and Index	15 months	36.9	American Society of Mechanical Engineers *J. Dimmer*
RP1338-4	Froth Flotation for Fine-Coal Cleaning	17 months	124.5	Envirotech Corp. *K. Clifford*
RP1340-90	Cosponsorship Agreement: Demonstration of Enhanced Evaporation and Crystallization for Treatment of Cooling-Tower Blowdown	17 months	25.0	Envirotech Corp. *W. Chow*
RP1412-6	Design Strategy for the Combustion of Coal-Derived Liquid Fuels	18 months	169.8	Massachusetts Institute of Technology *W. Rovesti*
RP1455-2	Evaluation of Coal-Oil Mixture Fuel for Electric Utility Application	17 months	599.1	Arco Petroleum Products Co. *S. Drenker*
RP1463-1	Feasibility Assessment of Fusion Fission Hybrids, Phase 1	2 months	100.0	Westinghouse Electric Corp. *N. Amherd*
RP1645-2	Preliminary Assessment of Pressurized Fluidized-Bed Combustion Power Plant Systems	6 months	82.8	Burns and Roe, Inc. *W. Slaughter*
RP1648-2	Assessment of Rotor Bearing Analysis Technique	10 months	100.0	Mechanical Technology, Inc. *J. Parkes*
RP1685-1	Update of Flue Gas Desulfurization Sludge Disposal Manual	1 year	95.4	Michael Baker Jr., Inc. *D. Golden*
Nuclear Power Division				
RP355-14	Engineering Services for Thermal Analysis, EPRI Test Reactor Experiments	8 months	20.0	General Electric Co. *G. Thomas*
RP810-8	Influence of an Aseismic Base Isolation System on the Response of Internal Equipment and Components	10 months	46.8	University of California *C. Chan*
RP814-3	Datatran Applications Support	13 months	50.0	Technology Development Corp. *R. Whitesel*
RP892-11	Ultrasonic System Analysis Support	6 months	93.6	Ultrasonics International, Inc. *M. Lapides*
RP1446-1	Power Plant Availability Engineering Program	10 months	124.2	Pickard, Lowe and Garrick, Inc. *J. Prestele*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1448-8	Nondestructive Examination Evaluation and Support	1 year	89.4	Bechtel National, Inc. *M. Lapides*
RP1449-3	On-Line Monitoring and Diagnostics for Turbines and Reactor Coolant and Charging Pumps	6 months	52.9	Pickard, Lowe and Garrick, Inc. *G. Shugars*
RP1553-1	Evaluation of Irradiation Response of Reactor Pressure Vessel Materials	22 months	170.6	Combustion Engineering, Inc. *T. Marston*
RP1553-2	Application of Adaptive Learning Network Modeling to Radiation Embrittlement	1 year	72.0	Adaptronics, Inc. *T. Marston*
RP1554-4	Leak Rates From Stress Corrosion Cracks in Boiling Water Reactor Piping	10 months	9.8	Failure Analysis Associates *R. Jones*
RP1554-6	Engineering Models for Predicting Stress Corrosion Cracking of Boiling Water Reactor Piping Welds	1 year	92.1	Science Applications, Inc. *R. Jones*
RP1554-7	Analysis to Predict the Shapes of Growing Stress Corrosion Cracks in Boiling Water Reactor Piping Welds	10 months	65.8	Aptech Engineering Services *R. Jones*
RP1562-1	Stress Corrosion Cracking Test Methods Applicability to Plant Performance	17 months	92.7	Aptech Engineering Services *J. C. Danko*
RP1573-1	Nuclear Plant Response to Grid Electrical Disturbances	13 months	200.0	EDS Nuclear, Inc. *G. Shugars*
RP1706-1	Development of Semiautomatic Weld Crown Contouring Equipment, Phase 2	1 year	99.1	Sigma Research Inc. *G. Dau*
RP1708-1	Optimization of Metallurgical Variables to Improve the Corrosion Resistance of Inconel 600	13 months	316.8	Westinghouse Electric Corp. *S. Laskowski*

Electrical Systems Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1291-2	Development of a Cesium-Vapor Lamp System for Triggering Photothyristors	2 years	97.0	General Electric Co. *G. Addis*
RP1498-1	Effects of Reduced Fault Duration on Power System Components	2 years	126.9	Stanford University *N. Hingorani*
RP1499-2	Power Transformer With Two-Phase Cooling	18 months	965.5	Westinghouse Electric Corp. *E. Norton*
RP1519-1	Determination of Maximum Safe Pulling Lengths for Solid Dielectric Insulated Cables	2 years	629.9	Pirelli Cable Corp. *R. Stanger*
RP1531-1	Determination of Torsional Fatigue Life of Large Turbine Generator Shafts	35 months	1102.0	General Electric Co. *J. Edmonds*
RP7877-1	Scoping Study, Cable Materials Research Center	7 months	17.0	Stone & Webster Management Consultants, Inc. *B. Bernstein*

Energy Analysis and Environment Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP434-37	Topic Paper: Customer Acceptance of Load Management	6 months	15.5	Temple, Barker & Sloane, Inc. *R. Malko*
RP1109-5	Lake Acidification Study	44 months	3228.1	Tetra Tech, Inc. *R. Goldstein*
RP1630-2	Eastern Regional Air Quality Studies: Precipitation Chemistry Measurements	18 months	811.8	Rockwell International Corp. *G. Hilst*

New Technical Reports

Each issue of the *Journal* includes summaries of EPRI's recently published reports.

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ELECTRICAL SYSTEMS

A New Class of Additives to Inhibit Tree Growth in Solid Extruded Cable Insulation

EL-530 Final Report (RP7851-1)

Various ionic additives were tested for use in extruded dielectric cables. Ferrocene (5%) was determined to inhibit tree growth in extruded dielectrics but oxidized both in air and in the presence of dicumylperoxide. Alpha-bromolauric acid was found effective in steel needle breakdown tests at 60 Hz but proved thermally unstable. Ferrocene-related compounds proved either ineffective or oxidatively unstable. The contractor is General Electric Co. *EPRI Project Manager: Felipe Garcia*

New Methods and Chemicals to Control Regrowth in Trees

EL-1112 Interim Report (RP214)

A portable air-powered equipment system was developed for injecting low volumes of concentrated aqueous chemical solutions into trees for sprout regrowth control. Greenhouse and field studies were conducted; chemicals were screened and evaluated; and variable factors affecting growth control were investigated and evaluated. Laboratory studies on the translocation and metabolic behavior of the regrowth-regulating chemicals are included, together with a cost analysis and discussion of the status of the chemicals. The contractor is the U.S. Department of Agriculture. *EPRI Project Manager: R. S. Tackaberry*

Contamination Detector for Extrudable Dielectrics

EL-1120 Final Report (RP7865-1)

This report describes the design, fabrication, and testing, both in a laboratory and cable plant, of an electrooptical defect-sorting system for the detection and removal of contaminated pellets prior to their entry into the cable insulation extruder. The report discusses the system's efficiency and the contaminant's nature, size, shape, color, and position within the pellet. Experimental data are contained in an appendix. The contractor is Reynolds Metal Co. *EPRI Project Manager: Bruce Bernstein*

Determination of AC Conductor and Pipe Loss on Pipe-Type Cable Systems

EL-1125 Final Report (RP7832)

Results of investigations on the determination of ac/dc resistance ratios of high and extra-high voltage pipe-type cables having large segmental conductors are presented in this report, which was jointly funded by DOE and EPRI. The measurements included 115-, 345-, and 765-kV cables with copper and aluminum conductors. The Neher-McGrath equations were confirmed and improved. The computer program developed only limited agreement between calculated and measured values. The contractor is General Cable Corp. *EPRI Project Manager: Felipe Garcia*

Dynamic Equivalents for Transient Stability Studies of Very Large Synchronous Networks

EL-1132 Final Report (RP763)

Expansion of the dynamic equivalent programs to handle very large systems in the size range of 8000 buses and 16,000 lines is described. This report also discusses compilation of a transient stability data base for the eastern United States and Canadian interconnected systems and installation and validation of the coherency-based dynamic equivalent programs for production study use by East Central Area Reliability Coordination Agreement. The contractor is Systems Control, Inc. *EPRI Project Manager: Nallicheri Balu*

Distribution Data Base Design

EL-1150 Final Report, Vols. 1, 2, and 3 (RP1139-1)

Volume 1 provides an explanation for the general reader of the strategy that was followed in reaching the logical design of the distribution data base. Included is documentation of the work performed, the work leading up to the design, each step in the design process, a number of practical implications, economic evaluation, results, guidance on cost-benefit analysis, and recommendations for future research. The functional capabilities of the distribution data base and its economic evaluations are described in Volume 2, which is oriented toward utility distribution personnel. Preliminary work to define the functional problem area, selection of the 25 functions to be supported, introduction to functional specifications, functional descriptions of the 25 functions, and ancillary distribution data base considerations are documented. Volume 3 presents the logical design and the physical implications of the distribution data base design. This volume is directed to persons interested or involved in the computer aspects of the distribution data base. A study of Volume 2 should be considered a prerequisite to using this volume. The contractor is Boeing Computer Services, Inc. *EPRI Project Manager: W. E. Shula*

ENERGY ANALYSIS AND ENVIRONMENT

Economic Analysis of Coal Supply: An Assessment of Existing Studies

EA-496 Final Report, Vol. 3 (RP335)

Three coal supply models (by ICF Incorporated, Charles River Associates Inc., and Martin B. Zimmerman) and a world energy model (by Virginia Polytechnic Institute and State University) are reported for the first time. Also included are other coal studies, surveys of the general coal market, examination of competition in the coal industry, coal mine costing analyses, and assessments of regional impacts of coal industry development. Problems in predicting coal industry development are discussed. The contractor is Pennsylvania State University. *EPRI Project Manager: T. E. Browne*

An Evaluation of the Pseudo-Data Approach

EA-1108 Final Report (RP867)

The pseudo-data approach to long-run energy modeling was critically appraised. The results suggest that (1) single-equation summarization is neither feasible nor desirable because it results in a loss of vital information; (2) the procedure used in generating the data points is not useful; and (3) methods used for approximating engineering process models are inadequate. Modifications and improvements to the approach are being made in a separate project (RP1149). The contractor is A. L. Fletcher & Associates. *EPRI Project Manager: A. N. Halter*

Methodology for Evaluation of Multiple Power Plant Cooling System Effects

EA-1111 Final Report, Vols. 1, 2, and 3 (RP878-1)

Volume 1 contains a general technical discussion and outlines screening procedures. Typical cooling system operation parameters, characteristics of different water body types, prescreening procedures, and an overview of detailed assessment methods are included. Volume 2 describes the technical basis for computations performed by various models. Volume 3 describes the data requirements for computations performed by various models. The contractor is Tetra Tech, Inc. *EPRI Project Manager: J. Z. Reynolds*

The Wharton Annual Energy Model

EA-1115 Final Report (RP440-1)

The report reviews the history and development of modifications to provide detailed capability for analyzing energy-economy relationships in the energy sector of the commercial econometric

Wharton Annual Model. Specific methodologies employed are described. The construction of satellite models that describe selected energy-related sectors in greater detail are reviewed. Proposed development, restructure, and revision of the model are included. The contractor is Wharton EFA, Inc. *EPRI Project Manager: Lewis Rubin*

Biological Effects of High-Voltage Electric Fields: An Update
EA-1123 Final Report, Vols. 1 and 2 (RP857-1)
The literature and ongoing research concerning field measurement and exposure protocol, the influence of power frequency electric fields on biological systems, and special issues, such as triglycerides and vibrational noise, are summarized in Volume 1. Survey article abstracts, research publication reviews, and a summary of Project Seafarer/Sanguine are also included. Volume 2 contains a critical bibliography covering the relevant papers and research reports published through mid-1977, as well as a summary of the most recent research projects. An index of subject and field characteristics is provided as a guide to the use of the bibliography. The contractor is IIT Research Institute. *EPRI Project Managers: Leonard Sagan and Harry Kornberg*

Mathematical Models for Atmospheric Pollutants
EA-1131 Final Report (RP805)
This report surveys the present and potential roles of quantitative models in air quality decisions. It also describes air pollutants and their sources, air pollution pathway processes, characteristics and classes of available atmospheric pathway models, and exposure and damage models, including esthetic effects (odor and visibility) and the assessment of the impact of pollutants on weather and climate. Four separately bound appendixes (A, B, C, and D, respectively) cover the meteorological elements important in the transport and fate of airborne pollutants, the important chemical and physical properties of gases and aerosols that determine the fate of airborne pollutants, the governing equations for the evolution and fate of airborne gases and particles, and the available models for the analysis of airborne pollutants. The contractors are Battelle, Pacific Northwest Laboratories and Decision Focus, Inc. *EPRI Project Manager: Dominic Geraghty*

Analysis of Bechtel's Regional Energy System for Planning and Optimization of National Scenarios (RESPONS) and ICF's National Coal Model (NCM)
EA-1133 Final Report (RP874-1-1)
Two coal models, ICF Incorporated's National Coal Model (NCM) and the Bechtel Regional Energy System for Planning and Optimization of National Scenarios (RESPONS), are analyzed and compared. The RESPONS model was run on the Pennsylvania State University computer; both the model and its output were reviewed. NCM was not run, but its assumptions were analyzed and sample outputs from other sources were reviewed. Recommendations for improvement of specific modeling methodology and data base improvements for both models are given. The contractor is Pennsylvania State University. *EPRI Project Manager: Dominic Geraghty*

Determining the Feasibility of Incorporating Water Resource Constraints Into Energy Models
EA-1147 Final Report (RP1304-1)
To express the availability of regional water resources with respect to energy production, a review was made of water resources data bases, technologies involved in energy development, and energy models with regional disaggregation. To study the feasibility of integrating the availabilities into energy-economy models, the Regional Energy System Optimization Model and the Energy Policy Model were used. Water resource constraints were introduced into the models, exploratory computer runs using demonstration scenarios were made, and a new regional scheme was proposed. The contractor is Stanford University. *EPRI Project Manager: Dominic Geraghty*

Survey of Existing Data Bases for Plume Model Validation Studies
EA-1159 Final Report (TPS78-806)
This report catalogs existing air quality data bases applicable to plume model validation studies. It is intended to be used as a reference to locate and acquire data bases for future plume model validation studies. The contractor is Form and Substance, Inc. *EPRI Project Manager: G. R. Hilst*

FOSSIL FUEL AND ADVANCED SYSTEMS

Solar Heating and Cooling Research Projects: A Summary
ER-1095-SR Special Report
Major EPRI solar heating and cooling projects are summarized. Each project is outlined, its purpose defined, and its major features described. Detailed descriptions of performance-monitoring equipment are included. *EPRI Project Manager: G. G. Purcell*

Development of Sulfur-Tolerant Components for Second-Generation Molten Carbonate Fuel Cells
EM-1114 Interim Report (RP1085-2)
Molten carbonate fuel cells were operated with sulfur-containing feed gases to identify their endurance, performance, and sulfur tolerance. Electrochemical half-cell measurements were made to identify the mechanism of sulfur poisoning. Cells were operated to verify performance gains and losses and to determine endurance limitations and other cell operating characteristics. Results show that carbonate fuel cells possess very poor sulfur tolerance. The contractor is Institute of Gas Technology. *EPRI Project Manager: A. John Appleby*

Sodium-Sulfur Battery Supporting R&D: An Evaluation of an Alternative Electrolyte and Battery Price
EM-1116 Final Report (RP726-2)
Part 1 of this report evaluates the sodium-sulfur battery with the sulfur electrode placed inside the electrolyte tube. Materials and fabrication costs of the unconventional English cell design are compared with those under development in the United States and elsewhere. Part 2 evaluates the fabrication process and properties of a new solid electrolyte (NASICON) and compares it with the present electrolyte (beta alumina). The contractor is Compagnie Générale d'Electricité. *EPRI Project Manager: J. R. Birk*

Diverse Liquefaction Behavior of Various Bituminous Coals in the SRC-I Process: An Engineering and Economic Evaluation
AF-1122 Final Report (RP411-2)
The technical and economic study conducted under RP411-1 was extended to include two additional solvent-refined coal (SRC) cases, Kentucky No. 9 and Illinois No. 6 (Monterey), to illustrate the effect of different feed coals on the liquefaction process. Typical operating conditions and yield structures were evaluated. The development of design concepts for the SRC process are summarized; total plant designs are discussed and described; and estimates of capital and operating costs are given. The contractor is The Ralph M. Parsons Co. *EPRI Project Manager: Nandor Herskovits*

Assessment of Fuel Delivery and Fuel Storage Alternatives for Dispersed Electric Utility Fuel Cells
EM-1124 Final Report (RP1349-1)
A parametric analysis of fuel transportation and storage costs was made by contacting regulatory agencies and transportation companies and developing their figures for a representative sample of U.S. metropolitan areas. The codes and regulations pertaining to the use of No. 2 fuel oil and naphtha were analyzed and tabulated. Costs were summarized in capital cost and operating expense tables for each area. A cost-of-service worksheet was devised and demonstrated to handle data for several modes of transportation and various fuel cell capacities. The contractor is Bechtel National, Inc. *EPRI Project Manager: E. A. Gillis*

Autothermal Reforming of No. 2 Fuel Oil
EM-1126 Final Report (RP1041-2)
Results of research to define the practical operating limits of the autothermal reforming process are presented. Experiments conducted with a 4-in-diam, 15-in-long catalytic reactor (nickel catalyst) to produce a hydrogen-rich gas from No. 2 fuel oil and steam-air mixtures are described. The hydrogen yield was mapped in the carbon-free region as a function of the major operating parameters, and the results were compared with the equilibrium yield predictions. Two optimal cases were identified. The contractor is California Institute of Technology, Jet Propulsion Laboratory. *EPRI Project Manager: E. A. Gillis*

High-Temperature Ceramic Heat Exchanger
FP-1127 Final Report (RP545-2)
The technology developed to design and construct a ceramic heat exchanger for operation with a small (200-hp) closed-Brayton-cycle engine is described in this report. The report also includes the design philosophy; an extensive material data base; heat transfer performance and pressure drop experiments, whose results are compared with predicted values; and reliability/lifetime predictions made for the complete heat exchanger assembly. Experimental data are contained in the appendixes. The contractor is AiResearch Manufacturing Co. of California. *EPRI Project Manager: R. H. Kinsman*

Building Energy Analysis Computer Programs With Solar Heating and Cooling System Capabilities

ER-1146 Reference Manual (RP1269-1)

This manual relates to computer simulation models and manual calculation methods for predicting the performance of solar heating and cooling systems. It focuses on programs that are available for use by the electric utility industry and its customers. Detailed characteristics of available programs are given by summary matrixes in 10 specific areas and by one-page summary descriptions for each program. Brief comments on programs, which are generally not available for public use, are also included. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: Gary Purcell*

Market Potential for Electrolytic Hydrogen

EM-1154 Final Report (RP1086-4)

Results of a hydrogen-demand survey of the chemical, pharmaceutical, food, metal, electronic, and float glass industries are presented, and the relative economics of steam-reformed and electrolytic hydrogen are calculated. A resultant market for electrolytic hydrogen is projected to the year 2000. The potential systems applications of electrolytic hydrogen by the electric utility industry are discussed. The contractor is The Futures Group. *EPRI Project Manager: Bhupen Mehta*

Screening Evaluation of Electric Power Cycles Integrated With Coal Gasification Plants

AF-1160 Interim Report (RP986-3)

The performance and cost potential of a relatively simple non-steam-bottomed gasification–combustion turbine system are described. Thermal efficiency is calculated and compared with the efficiencies of several steam-bottomed cycles. Major development requirements for each configuration are identified, and development program difficulties are estimated. Results of an economic overview to determine the level of capital cost savings needed for the non-steam-bottomed system to be competitive with the steam-bottomed cycles are presented. The contractor is General Electric Co. *EPRI Project Manager: M. J. Gluckman*

NUCLEAR POWER

LMFBR Pool Plant—1000 MW (e): Executive Summary

NP-1015-SY Final Report, Vol. 1 (RP620-21 and RP620-22)

The first of a four-volume final report summarizes the results contained in previous interim reports and gives additional information on plant transients and pool thermal-hydraulic effects; vibration effects induced by seismic, mechanical, and hydraulic activity; and safety criteria and methodology to support U.S. licensing. The contractor is Bechtel National, Inc. *EPRI Project Manager: Joseph Matte III*

Uranium Isotopic Separation by Aerodynamic Methods

NP-1069 Final Report, Vols. 1 and 2 (RP506-1)

Jet membrane and velocity slip processes, two aerodynamic separating techniques for uranium enrichment, were investigated and compared through analytic and laboratory studies for technical feasibility and economic viability. Costs of the two processes are compared. Project work on jet membrane isotope separation process is summarized. A review and a compendium of the velocity slip isotope separation process are presented. The contractor is COE Associates. *EPRI Project Manager: M. E. Lapides*

Human Factors Methods for Nuclear Control Room Design

NP-1118-SY Summary Report (RP501-3)

Human factor techniques applied in the design of nuclear power plant control panels are documented, and methods for upgrading existing panels are examined. Designs to improve the operator–control board interface were limited to reactor, feedwater, and turbine-generator control panels and were based on analyses of startup, change of power level, and shutdown operations. Special attention was given to warning-system designs. Results of a survey of control board designers and future research direction recommendations are included. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Manager: R. W. Pack*

Status Report on the EPRI Fuel Cycle Accident Risk Assessment

NP-1128 Interim Report (RP767-1)

This report is the first in a series that will document societal risks of all important processes of the external nuclear fuel cycle. Draft documents on five operations that analyze the risks posed by each of these processes are summarized and extended. These consider the accidental radiological risk of spent-fuel reprocessing, mixed-oxide fuel fabrication, the transportation of materials within the fuel cycle, the disposal of nuclear wastes, and the routine atmospheric radiological risk of mining and milling uranium-bearing ore. The contractor is Science Applications, Inc. *EPRI Project Manager: G. S. Lellouche*

Comparison of the EPRI and Lewis Committee Reviews of the Reactor Safety Study

NP-1130 Interim Report (RP1233)

The draft version of the Reactor Safety Study (WASH-1400) was reviewed by EPRI in two publications; the final version of WASH-1400 was reviewed by the Lewis Committee of the National Regulatory Commission. This report compares the Lewis Committee review with the summary and critique prepared by EPRI. Two exceptions to general agreement on issues were the ATWS issue and the relative conservativeness of the numerical results. This report demonstrates that the numerical results cannot be significantly optimistic and are probably quite pessimistic. The contractor is Science Applications, Inc. *EPRI Project Manager: G. S. Lellouche*

Experimental Study of Single- and Two-Phase Flow Fields Around PWR Steam Generator Tube Support Plates

NP-1142 Final Report (RP1121)

Local mean axial velocities and turbulence intensities at selected locations within a study model dimensionally prototypic of an existing PWR steam generator design were measured, using laser-Doppler anemometry. Single-phase water flow fields were investigated. Normalized velocity and turbulence intensity ratios are presented graphically. A qualitative investigation of two-phase flows near the support plate by using metered air-water mixtures in combination with high-speed motion picture techniques was conducted and is discussed. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: Henry Till*

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