DOE/CE/90142--T1

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DE89 015477

Issues in Electric Energy Systems

A Review of the DOE R&D Program

A Report Prepared by the
Committee on Electric Energy Systems
Energy Engineering Board
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1986

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This is a report of work supported by Contract No. DC-AC01-84CE90142 between the U.S. Department of Energy and the National Academy of Sciences.

Copies available from:

Energy Engineering Board
Commission on Engineering and Technical Systems
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

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PREFACE

This study was undertaken in response to a request to the National Research Council's Energy Engineering Board by the Department of Energy (DOE) to review the need for research related to electric energy systems and to review the DOE's program in this area. The DOE's Electric Energy Systems (EES) program is directed toward the power-delivery portion of a utility system, that is, from the electric generator to the customer's meter.

In response to this request the Energy Engineering Board established a committee of thirteen members to carry out the following tasks:

- Identify, characterize, and give priority to the long-term energy systems issues.
- Broadly define the federal role in electric energy systems R&D.
- Review the goals and objectives of the electric energy systems program.
- Organize a workshop to discuss the major research issues facing the program.
- Prepare a report on its findings, conclusions, and recommendations.

To gain a broad perspective and a better understanding of the issues, the Committee organized a two-day workshop, which was held on April 24-26, 1985.* Experts from different fields were invited to present papers on research related to the particular needs of the electric power systems sector.**

The general purpose of the workshop was to help the Committee understand the range of complex R&D problems and decisions that relate to the future of electric energy systems. These include: advanced systems technology involving new materials, concepts, and components; reliability involving the use of communications and computer technology for normal and emergency operations and the special national defense contingencies associated with an electromagnetic pulse from a nuclear device exploded in the atmosphere; and environmental impacts

*See Appendix A for the workshop program.
**See Appendix B for a listing of workshop participants.

related to the effects and magnetic fields induced by high-voltage transmission lines.

The specific objectives of the workshop were to identify research topics that are of national importance, determine the appropriate federal role vis-a-vis the private sector, and critique the current and planned EES program in the light of these considerations.

In addition to the specialists who presented papers, a panel of experts on electric systems was invited to address the issues and to offer views of the research and development needs of the electric sector. Finally, invited guests included congressional staff, DOE personnel, and industry specialists, who attended the meetings and contributed to the discussions.

The results of the workshop have been published in a separate volume titled Papers Presented at a Workshop on Electric Energy Systems Research (NRC, 1985b).

Using the findings of the workshop, the Committee established a schedule and plan for the remainder of the study. The main emphasis was to define and characterize an appropriate federal role in supporting R&D to help solve the technical problems of the electric power industry. Referring to the first task--"identify, characterize, and give priority to long-term energy systems issues"--the Committee identifies and characterizes in detail what it considers to be the salient long-term systems issues. However, it does not attempt to prioritize these issues for the purposes of budgeting and allocation because it considers this task to be the job of the EES. The Committee believes this report will help the program in that regard.

While this report is addressed to DOE as the sponsoring agency, the Committee hopes that it will be of interest to energy policymakers, electric utility managers, persons in private sector research organizations, university laboratories, and in general those interested in electrical energy and public policy.

The Committee would like to thank Dennis Miller, executive director of the Energy Engineering Board, for organizing and supervising this effort, and Frederic March, study director, who worked with the Committee in preparing the report. The Committee also thanks Rosena Ricks, Cheryl Woodward, and Helen Johnson for their role in organizing the workshop and other meetings and in helping to prepare this report, and Michael Hays, editorial consultant.

Andrew F. Corry, Chairman
Committee on Electric Energy Systems

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EXECUTIVE SUMMARY

INTRODUCTION

To put the Electric Energy Systems (EES) program into perspective, this report begins with an in-depth review of the historic federal role in energy research and development. This review supports the Committee's opinion that federal support of research and development (R&D) in this area is warranted by a combination of federal policy and private-sector considerations (chapter 1).

The report then examines the major categories of R&D requirements related to electric power systems: systems technology; reliability; and safety, health, and environment (chapters, 2, 3, and 4). These chapters establish the need for specific research topics recommended by the Committee and also provide a critique of the current EES program plan.

In the final chapter the Committee presents its critique of the EES history and current operations. It then provides summary views of the program management requirements and the general budget to carry out the Committee's recommendations.

In summary the Committee finds:

- Federal support of electric energy systems R&D is warranted by past and current administration criteria for general support of energy R&D.
- There is a national need for continuing research, which would not otherwise be done in systems technology; reliability; and safety, health, and environment (for the electric power industry).
- The private-sector combination of electric utility companies and equipment manufacturers is not making an adequate investment in long-term R&D for a variety of reasons and is thus leaving a number of R&D gaps unfilled.

- Historically and currently, the EES program has not been in a position adequately to perform the role for which it was created. Several deficiencies, including budgetary support, need to be corrected if the EES program is to fulfill its mission in a meaningful way.

THE FEDERAL ROLE IN ENERGY RESEARCH AND DEVELOPMENT

The current administration's criteria for allocating funds to energy R&D include the requirements that private investment be insufficient and that the potential payoff be large in terms of national benefits. Typically the private sector will avoid investments in R&D when the investor cannot share in the benefits in a substantial way. The result is underfunding of programs that may be in the national interest. Such underfunding may occur when the benefits are environmental, social, cultural, and military--benefits that do not lend themselves to private investment. Underfunding may also occur in relation to programs that are economically valuable, such as those enhancing energy efficiency or reliability, especially when circumstances related to scale of the investment, time to payoff, and government regulations tend to inhibit private investment.

The nation depends on an economical and reliable network of electric energy systems. These systems are built and operated by an electric power industry that recognizes the need for a continuous R&D effort to improve operations, increase efficiency and reliability, and maintain reasonable costs of service. A considerable investment in R&D for the industry is made through the Electric Power Research Institute (EPRI), and there are many individual utility R&D programs that in 1977 matched EPRI's expenditure (EPRI, 1980). EPRI's 1985 budget of $268 million covers the following R&D areas: coal combustion systems, nuclear power, advanced power systems, electric systems, energy analysis and environment, and energy management and utilization. Most of this research is funded with the pooled contributions of EPRI members. It would not otherwise be funded by the utility companies on their own.

Even though EPRI R&D expenditures as well as those of individual utilities are substantial, they are insufficient in relation to national needs. EPRI and other industry R&D programs concentrate on projects that have a high probability of producing commercially useful results for the industry in the near term, that is within ten years. Thus long-term R&D needs related to innovative technology developments through the end of the century and beyond are for the most part not addressed. In addition the industry does not adequately support R&D in certain areas of national concern, such as the biological effects of electric and magnetic fields, and defense of electric systems against electromagnetic pulse. Most importantly EPRI and the industry suffer a problem of credibility with respect to the former issue; and in respect to the latter they feel too remote from the technical military issues. For these reasons the federal government for many years has continuously funded R&D programs that in substance and level of effort went beyond EPRI and industry R&D programs. This report focuses on one of the smaller federal programs in the Department of Energy's Office of Conservation--the Electric Energy Systems (EES) program--which concentrates on transmission and distribution systems from the station busbar to the customer's meter.

In 1985 EPRI allocated about $45 million to electric systems R&D in categories similar to those on which EES programs spent about $21 million. Referring to all electric utility research, including electric systems, EPRI has stated, "The resources now being devoted are inadequate. The industry is barely meeting its current technology challenges. As a high technology industry it is not doing enough to pave the way to a solid future" (EPRI, 1984b). The Committee finds that the EES effort correspondingly falls short and does not even adequately complement the existing EPRI electric systems effort. The combined commitment falls short of the national need in that many innovative and important long-term R&D projects are either unfunded or underfunded.

The Committee concludes that:

- There is a legitimate federal role for energy R&D in general, which has proven correct historically and which has validity in terms of the criteria established by the current administration.
- The need exists for long-term technologically innovative projects offering major potential national benefits at a time when industry fails to invest in such projects for reasons relating to the ability to recover their investments and appropriate the benefits.
- Additional need for federal R&D support is caused by national defense, environmental, safety, and public health considerations.
- In particular, R&D in the electric power industry for transmission and distribution of electricity is considerably underfunded in relation to proven national needs and requirements.
- Failure of the government to help respond to the future needs of the electric power industry will produce future social costs in the form of higher operating costs, lower system reliability, higher environmental impacts, and increased dependence on foreign suppliers for critical high-technology components.
- Therefore, specific federal R&D programs in support of the nation's electric energy systems, as described in the following section, should be implemented.

SYSTEMS TECHNOLOGY

Systems technology relates to the integration of technology and systems for delivering power in a controlled and economical manner. This is an area in which the federal role should ideally be minimal, much in the same way that the development and deployment of new technology is the purview of the private sector. While the power industry and its equipment suppliers are to a large extent the creators of new and innovative technology, the Committee believes that the industry is unable adequately to capture the long-term benefits of many important technologically innovative areas. This inability then inhibits an adequate level of investment, particularly for projects whose payoff is long term. Historical evidence for this is the increasing U.S. dependency on foreign suppliers for modern electric systems components, such as transformers and circuit breakers, and a decreasing volume of exports of U.S. electric equipment. The situation is caused by a combination of factors--the recent slow-growth and low-growth projections of the U.S. power industry and its decreasing role as a market for innovative new technology, foreign government support of systems technology development, and inhibiting factors related to the U.S. regulatory environment.

The Committee recognizes the underlying factors, but to recommend economic and trade policy changes is beyond its scope. Assuming that this adverse situation is likely to prevail for some time, the Committee recommends that DOE's EES program continue selectively to support significant long-term innovative systems technology R&D to ensure continued U.S. progress in critical areas. The Committee's critique of the current EES portfolio in systems technology is provided in chapter 2 and summarized on Table ES-1.

RELIABILITY

Conventional Reliability Issues

The reliability of the nation's electric power networks as measured by the low rate of customer service interruptions is very high. The economic and social costs of interruptions are also correspondingly high. Therefore continued efforts to maintain and enhance reliability are warranted.

The reliability of complex electric power transmission and distribution systems depends on the integrated performance of a variety of subsystems and components: the systems technology and the reliability of individual components, the ability to predict adverse events, the ability to detect incipient conditions of failure in the field, the ability to communicate field conditions to an analysis and control center, the ability to analyze large amounts of input data, and the ability to respond and take corrective action.

Table ES-1 Systems Technology Research Recommendations

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
<u>Components and materials</u>			
New materials	1.0	Improve fundamental electric, magnetic, mechanical, and optical properties	Evaluate new concepts in transformer cooling; DC circuit breakers; and high-voltage, high-capacity AC circuit breakers
			Identify currently used processes and dielectric magnetic core and conductor materials that can benefit from improvements
Electric insulating materials	1.0	Develop superior liquid, solid, and gaseous dielectric materials	Develop a fundamental understanding of aging and associated failure mechanisms of dielectric materials
			Investigate fundamental mechanisms and interfacial phenomena of dielectric materials--liquid, solid, and gaseous
Power semiconductor concepts	1.5	Develop crystalline and amorphous semi-conductor materials and other materials concepts	- - -

Table ES-1 Systems Technology Research Recommendations (Continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Alternative delivery systems			
Superconducting power delivery	1.0	Develop advanced cost effective cryogenic cable insulation	Continue R&D on superconducting transmission lines
Superconducting technology	1.0	Develop power equipment concepts. Investigate underground AC cables, advanced concept synchronous generation, and cryogenic refrigeration	- - -
High voltage direct current	3.0	Advance the state of the art to achieve higher efficiency at lower cost	Perform research in HVDC to include forced commutation circuits (new bridge configurations, new power semiconductors), system studies (multiterminal lines, urban applications coordinated AC/DC systems)
Automation and processing concepts	2.0	Perform automation and control experiments, communications, protocol studies, and applications of fiber optics	Develop ways to retrofit existing facilities for higher capacity and with less impact on the environment. Investigate dispersed generation--cogeneration, windfarms, low-head hydro, and other growing dispersed technologies

Table ES-1 Systems Technology Research Recommendations (Continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Decision analysis and control	0.5	Develop expert computer systems for information processing to assist decision making in operations and in expansion planning	- - -
Hawaii Deepwater cable	5.8	Technical and economic feasibility study of Hawaiian Islands submarine DC power cable	Phase out the Hawaii Deepwater cable project
<u>Load leveling and energy management</u>			
BEST/load leveling	0.8	Test advanced batteries under realistic utility operating conditions, in order to prove prototype system concepts	Participate in a coordinated national program of advanced compressed air energy storage
			Perform exploratory R&D for alternate electrochemical and chemical systems for load leveling and energy storage

Table ES-1 Systems Technology Research Recommendations (Continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Advanced battery systems integration	1.0	Develop prototype design concepts for utility load leveling applications to be tested at BEST facility	Explore technical and economic prospects for superconducting magnetic energy storage Explore new techniques for cool storage Identify the benefits of integrated planning and operation for supply-side and demand-side energy management systems

Thus R&D is needed at many levels in the electric system to enhance reliability and reduce associated costs. As with systems technology, a certain level of R&D on reliability is being done by the private sector. The R&D stresses short-term results of immediate use to the industry. However, there are important long-term R&D issues that the federal government should recognize and to which it should respond. Thus the Committee recommends that the EES program selectively support R&D on reliability, as described in chapter 3 and summarized on Table ES-2.

National Defense: Electromagnetic Pulse (EMP)

The ability of the nation's electric power systems to function during a national emergency such as a nuclear attack is primarily a concern of the Department of Defense (DOD). The effects associated with a high-altitude nuclear burst, especially the effects of EMP, are the subject of research by military planners.

While the potential vulnerability of the nation's electric power systems is recognized, very little is known about how these systems will actually respond to EMP, let alone how to protect them and reactivate them rapidly. The agencies currently studying EMP, the Defense Nuclear Agency and the Air Force Weapons Laboratory, lack the specific electric utility systems expertise. However, defense planning against such attack necessarily involves the participation of the electric power industry.

Thus the Committee believes that the appropriate civilian focus for EMP research is DOE's EES program, which is in the best position to communicate with both the electric power industry and DOD, to elicit cooperation from all parties, and to provide the public with accurate and meaningful information.

SAFETY: ELECTRIC AND MAGNETIC FIELDS (EMF)

As power companies construct new transmission and distribution facilities, they must prepare an environmental impact statement (EIS) disclosing all forms of potential environmental impact. The major concern here is the potential impact of electric and magnetic fields associated with any electric conductor. At the high voltages of modern transmission systems, the health and safety of humans and animal life near such lines is of concern.

The research literature in this field is beset with conflicting claims about biological effects and questions of rigor in the application of scientific methods. As a result there has been extended and acrimonious public controversy, and the perception has been created in the minds of many interested parties that industry-sponsored research in this area lacks credibility and in some cases validity.

Table ES-2 Recommendations on Reliability Research

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and and Recommended Topics
Conventional reliability research			
Normal/emergency operating concepts	1.6	Develop methods, strategies, and concepts for system operations by using advanced microcomputer technologies, particularly for abnormal operations	Some of the issues in new bulk power transmission facilities in need of resolution include predicting the risks and costs of widespread interruptions and assigning values to transfer capability which take into consideration reserves and load diversity benefits during strategic emergencies
Failure mechanisms	0.4	Develop a fundamental understanding of the failure mechanisms due to the aging of dielectric insulating materials used in cables, capacitors, transformers, motors, and generators	Given the key roles of security and integrity that protection and control systems play in power systems, incremental cost/benefit assessments are needed to evaluate the economic merits of improving the security and dependability of these systems; and of reducing, the risks of line failure because of lighting, fault clearing, or switching surge
Computeraided control	0.3	Improve the ability to measure the dynamic changes in electric power systems in real time	Reliability R&D should emphasize control strategies for limiting the area of outage, for making early detection, and for restoring power

Table ES-2 Recommendations on Reliability Research (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and and Recommended Topics
		in order to expand the use of microprocessors in the control and protective processes	rapidly. There should be a continued strong effort to develop computer models which can simulate operation of very large integrated systems under a great variety of stresses Opportunities exist for increasing power transfer capability of existing facilities and rights of way, of mitigating the environmental impacts, and of minimizing land or space use to penetrate dense load areas Review the philosophy of continentwide synchronous systems The cost and reliability effectiveness of asynchronous interconnection of regions and power pools should be investigated
HVDC control/ protection	0.5	Verify and enhance control concepts	An assessment should be made to evaluate the economic merits of control capabilities for rapid reconfiguration, re-energization, and restoration, as opposed to reducing the risks of failures in the bulk power supply system

Table ES-2 Recommendations on Reliability Research (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and and Recommended Topics
National defense issues/EMP			
Electromagnetic pulse analysis	3.0	Develop analytical and modeling techniques to determine magnitude of EMP effects on electric energy systems. Investigate protection, control, and operating strategies to mitigate those effects	Develop scientific and improved statistical models for representing the the influence of EMP on electric power systems Develop state of the art analytical methods for assessing the effects of EMP on electric power systems to EMP effects
Electromagnetic pulse impact mitigation	1.5	Develop options on how to harden the electric power network or to suppress the EMP transient	Develop and evaluate technologies and integration techniques designed to minimize the influence of EMP on electric power systemes Provide information and recommendations for electric power structural and operational requirements when subjected to EMP disturbances

The Committee finds that EES efforts in this field have failed to meet rigorous scientific standards and have in other ways fallen short of the national need to provide definitive answers to critical questions about so-called biological effects. In many of these EIS there are problems of budgets that are too low, poor research design, and failure to identify the most competent researchers. These problems should be remedied by providing additional funds, adding staff with the relevant expertise in biology, and instituting a peer review system for R&D funding.

Therefore the Committee recommends that the EES program considerably upgrade its efforts as a neutral sponsor of research in this controversial area. The Committee's critique of the current EES program relating to the safety of electric and magnetic fields is provided in chapter 4 and is summarized on Table ES-3.

ELECTRIC ENERGY SYSTEMS PROGRAM IMPLEMENTATION

DOE's current EES program was originally created in 1970 as part of the Department of Interior. As the government responded to the energy crisis in the wake of the 1973 oil embargo, the EES program grew, moving to the Energy Research and Development Agency (ERDA) and finally to the Department of Energy. By 1980 the program had a budget of $38 million and a staff of 28 professionals.

Beginning in 1981, the program was affected by the new administration's introduction of its own criteria for examining all federal expenditures. By 1985 its budget had been cut to about $21 million and its professional staff to only three people. Thus the program has failed to meet such key criteria for a successful R&D program as stability of funding and continuity of dedicated and expert staff.

Recently the administration has requested only $10 million in new funds for the EES fiscal year 1986 budget, to which the respective congressional appropriations committees have added $2 million. In addition, $8 million is to carry over from fiscal year 1985, three-fourths of which is for a single project ranking very low on the EES multiyear plan priority list (The Hawaii Deepwater Cable is ranked 18th in a group of 20; see Table 5-1). Subtracting the Hawaii project and nondiscretionary program activities (Table 5-1), only $10 million will remain in fiscal year 1986 to cover all the other research needs in three program areas: systems technology, reliability, and safety that is, the effects of electric and magnetic fields). This budget is considered by the Committee to be grossly inadequate in relation to the national need.

Table ES-3 Recommendations on Safety: Electric and Magentic Field Effects

EES Proposed Topic	EES FY86 Budget ($ million)	EES Topic Description	Committee Comments And Recommended Topics
Short-term program			
Biological research AC	3.3	Establish an obejctive scientific data base of electric field effects, their thresholds of occurance, and the biological mechanisms by which effects are produced	For both AC and DC, short-term basic research components should aim to establish exposure guidelines based on dose-response curves for biological effects Develop a dosimetric basis for extrapolation of results from animal studies to humans
		Begin a program to determine the impact magnetic fields on human and health safety	Epidemiological studies of program to transmission-line field effects should begin immediately
Long-term program			
Biological reserach DC	0.9	Establish an objective scientific data base of DC electric field effects, ions, their thresholds of occurance, the biological mechanisms, and risk potential to humans	For both AC and DC, long-term basic research should have the objective of determining the mechanisms of interaction between AC/DC electric and magnetic fields and biological tissue

Based on its review of the program, it is the Committee's judgment that the EES program should be annually funded at a level of at least $45 million. This is based upon the following considerations:

- The Committee recommends that $12 million annually be spent on electric and magnetic field effects research, as discussed in detail in chapter 4.
- The Committee recommends that the nondiscretionary budget be increased to $5 million in order to support additional needed professional staff, as indicated in chapter 5.
- The remaining $28 million should be used for systems technology and reliability research and represents only a small increase over the DOE's proposed multiyear plan (DOE, 1984b). The need for the specific projects to be supported is described in detail in chapters 2 and 3.
- The effort of the electric power industry through EPRI alone is about $43 million in areas parallel to the EES program. The EPRI program concentrates on short-term R&D projects and does not effectively address the more long-term and innovative technology areas (chapter 1). A complementary federal effort by EES is needed.

In addition to the support of technical R&D programs, the Committee recommends that

- Special attention should be paid to the need for attracting competent graduate students into the field of electric power to serve as researchers, designers, operators, and managers. This should be done by linking support of graduate students to EES university contracts.
- EES should include a public information function as part of its program in order to prepare data for the Energy Information Administration and to improve communication of its program efforts to other federal organizations and to the general public. Because EPRI and EES will often work on parallel, complimentary R&D programs, it will be useful to coordinate public information programs.

1

THE FEDERAL ROLE IN ENERGY RESEARCH AND DEVELOPMENT

OVERVIEW OF THE FEDERAL ROLE

Brief History

The past fifteen years have witnessed notable shifts in the federal role in energy research and development (R&D). In the 1970s the federal government adopted a primary role in energy R&D on the assumption that government intervention was the best approach for addressing such problems of the energy crisis as drastically higher oil prices and sudden disruptions of supply. Indeed, the continuation in force of wage and price controls begun a few years earlier made the application of government regulation and price controls to energy markets a logical extension. Because short-term problems have an immediate urgency and are more politically pressing than long-term perceptions, the government's energy R&D efforts accordingly emphasized short-term results by making proportionately larger investments in development than in research and by stressing applied research over basic research (Darmstadter, Landsberg, and Morton, 1983).

The 1980s have seen a major redefinition of the federal role in energy research. Building on earlier modest efforts at deregulation and price decontrol, the current administration has espoused and executed a policy that has defined the role of the federal government in all markets, including energy markets, as secondary, necessarily interventionist, and a last resort. The administration thus believes the government should promote markets that are as free and unfettered as possible. To this end the federal government now seeks to minimize its participation in, and even to withdraw from, markets whenever possible. In this way it hopes to eliminate unnecessary government regulations that distort market operations and to adopt market-sensitive means that moderate government influence when overriding national interests require federal participation.

Current Federal Criteria

An overriding issue regularly arising in discussions of criteria for government funding of R&D programs is the proper division of effort between the government and the private sector. The administration's position is that federal government involvement in the commercialization of new technologies should be minimized and that free-market mechanisms should determine what R&D investments are made in such long-term and high-risk technologies as, for example, fusion energy.

In conformity with this view the Department of Energy (DOE) was authorized to spend $16.1 billion in fiscal year 1985 (OMB, 1984). Of this total about half is clearly related to defense, leaving $7.798 billion for energy programs that are largely civilian. Of this portion the following represent mainly R&D programs:

Programs	Cost
Energy Supply R&D	$1.955 billion
General Science and Research	0.727
Energy Conservation	0.458
Fossil Energy R&D	0.287
Total Estimated R&D	$3.427 billion

The administration requires that the potential payoff from these R&D investments provide high long-term national benefits and that the incentives for and the availability of private investment in such R&D be either severely limited or nonexistent (DOE, 1984b). Accordingly the administration has dedicated a large fraction of energy supply R&D to research on technologies such as fission and fusion.

The administration has advanced several arguments for a limited federal role in energy R&D. Foremost among these is that historical experience demonstrates the success of the free market as a generator of new technology. Other arguments essentially explain why free markets are more efficient means of achieving socially desirable ends. These include the following (Marcus, 1985):

- Small infrastructure. Free markets do not require the large infrastructure that federal R&D programs do and that is inherently inefficient.
- Greater diversity through decentralization. Industry R&D programs, unlike federal programs, are decentralized, competitive, and hence more diverse.
- Fair competition among energy sources. Federal energy R&D subsidies favor some industries over others.
- Greater adaptability to local needs. A diminished federal role encourages regional and state initiatives.

- Greater federal economy. Monies saved in energy R&D programs, especially large-scale demonstration projects, can be applied to more essential purposes.
- Efficient allocation of costs. A free market is a more efficient means of allocating R&D resources than the federal government is.

Thus current administration policy emphasizes that free-market mechanisms should largely determine what R&D investments are made. It also emphasizes that federal investment should be limited to those opportunities that offer large potential benefits to the nation in the long run, but that also involve risks to the private-sector investor high enough to deter funding support by industry (DOE, 1984b). This policy does not imply a halt to federally supported energy R&D; it does imply a federal R&D program tailored to supplement and support private-sector energy R&D activities (Marcus, 1985).

Rationale for a Federal Role

A free market itself has imperfections, and it is often in the national interest to seek remedy through government participation (Brooks, 1985). Just as there are arguments for circumscribing the federal role, there are also arguments for a continued support of energy R&D, including the following (Marcus, 1985):

- National security and emergency responses. The potential effects of large-scale hostilities or disasters are traditional concerns of the federal government and may require energy R&D to help prevent or mitigate them.
- Competitiveness of international markets. The federal government can confront the policies of other nations which impair the competitiveness of U.S. industry in both domestic and foreign markets.
- Compensation for other federal policies, programs, and activities. Federal regulatory, economic, trade, taxation, and other policies, programs, and activities may inhibit private-sector investment in energy R&D and may need redress through a compensating federal role in energy R&D.
- Underinvestment or inappropriate investment. Industry generally pursues short-term, revenue, or profit-oriented policies that inhibit investment in long-term energy R&D in the national interest.
- Social needs. The regressive effects of high energy prices may require energy R&D to moderate prices and perhaps reduce profits.
- Inefficiencies of competition. Competition among corporations may encourage cautious conformity to conventional energy technologies rather than diversity and innovation in energy R&D.

There are additional considerations favoring a federal role in energy R&D:

- Credibility of the research sponsor. The government routinely undertakes R&D to ensure that accepted standards of safety, health, and environment are satisfied. The private sector, which is widely perceived as motivated largely if not only by private gain, lacks the credibility to establish that its R&D programs give adequate and unbiased consideration to these factors. Only the federal government has the potential credibility to address public concerns in these areas.
- Stability of funding. Fluctuations in the economy generally and in energy markets in particular mean that private-sector investment in energy R&D will correspondingly fluctuate. When the electric utility industry suffers financial reverses, as it has during the past ten years, it sharply reduces its energy R&D investment (Crawford, 1985; EPRI, 1980). If the federal government also reduces its energy R&D investment when the economy is contracting and increases it when the economy is expanding, it magnifies the problems of managing effective energy R&D programs. Instead the federal government should provide a level of energy R&D investment that ensures continuity and stability in energy R&D efforts.

LIMITS ON PRIVATE-SECTOR INVESTMENT IN ENERGY R&D

In a review of the federal R&D policy, it is important to understand the reasons why the private sector may fail to invest in R&D up to an optimal level. When such underinvestment occurs, there are three policy choices: direct government investment, new policies that stimulate private-sector investment, and no action. The first option is appropriate when a compelling national interest can be demonstrated. The second is typically applied to situations in which government regulatory, fiscal, and financial policies are perceived to be inhibiting private-sector investment. Following is a discussion of some circumstances explaining underinvestment in energy R&D.

Appropriability of Benefits

The overriding consideration for energy R&D investment is the ability of the investor to appropriate the benefits of the investment costs. The individual corporation may be unable to appropriate fully the benefits for a number of the following reasons.

Externality

External benefits are those that in principle do not accrue to the private investor. These include a wide range of social benefits--national economic returns (as when fuel consumption is reduced), environmental enhancement, national security, social satisfaction, and intangible cultural benefits.

Patent Law Limitations

Many of the results of R&D fall into the category of general knowledge and may not be subject to patent. Other results, while patentable, may be difficult to protect in a practical manner against imitation. Unless investors are confident that they will recover their investment and realize a profit before competitors who use their results, they will avoid investment.

Changing Role of Technology

The business environment of the electric utility industry has changed from a past in which planning was driven by technology to one in which it is driven by the market. In the early days of the electric utility industry, the availability of technology to provide electric service for the first time posed the problem of how to provide the service as rapidly as possible to an almost unlimited market; that is, the technology itself stimulated or drove the market. Today with a mature market already served, the market is said to drive the technologies; that is, planners seek technological solutions through R&D to problems of reliability and efficiency. Private-sector R&D has been strongly shaped by this change in the nature and direction of the electric utility industry in the past decade.

Utility Regulation as a Limiting Factor

Regulation has special significance in the energy field because both electric and natural gas utilities are monopolies subject to regulations affecting prices, investments, and yield to investors. As a result even the expenditures for R&D may become subject to regulation (Stalon, 1984).

While regulatory policies among the various 50 state jurisdictions vary widely, there is almost always either an implicit or explicit requirement that R&D activity be justified to the regulator on some basis if its costs are to be recovered through rates. As a rule regulators allow the costs of successful R&D that benefits electric consumers to be added to the rate base. They usually disallow the costs of experimental or unsuccessful R&D. As a result utilities select short-term energy R&D projects with a high probability of technical success and thus a high probability of having its costs included in the rate base (March, et. al., 1981; Gerber, 1985a; NRC, 1986b, Gerber).

But such energy R&D is not likely to be very innovative. Even in the more enlightened jurisdictions, regulatory rate-setting procedures sustain only low-risk development efforts with incremental benefits to customers and investors rather than long-term innovative research efforts that may result in technological breakthroughs.

As a consequence, such R&D is considerably underfunded in relation to longer-term national needs (Manella, 1985; EPRI, 1984b).

The Doctrine of Federal Irrelevance

The electric utility industry thus operates in a business environment that combines features of both free and regulated markets, some of which inhibit the range and level of appropriate energy R&D investment. Accordingly, what may be called the doctrine of federal irrelevance, which asserts that government-sponsored R&D is irrelevant to any realizable benefit to customer or investor and wasteful of federal funds, is surely an incorrect one. Electric utilities are a part of the market and have good and sufficient reasons for making market-oriented choices for energy R&D investments. But the federal government is not a part of the market, has different reasons for making its choices, and has different choices to make. Those choices clearly transcend commercially directed decisions dominated by a short-term return on investment.

THE NEED FOR A FEDERAL ELECTRIC POWER RESEARCH PROGRAM

Electricity Supply and Market Growth

An electric energy system that is a reliable supplier of sufficient electric power to meet the nation's needs is vital to the economic health of the United States. For over a hundred years the electric power industry has successfully met those needs. During the past year alone, the United States consumed about 2.37 trillion kilowatt-hours (kWh) of electric energy, with an average service availability of 99.98 percent. During 1984 the typical U.S. customer experienced only 1.65 interruptions of electric power, and they lasted an average of 68 minutes (NRC, 1985b, Ringlee). Most of these interruptions occurred in lower-voltage distribution systems at the local level and were caused by storms, falling trees, and other such external events. Few interruptions were caused by transmission or regional distribution system failures.

This remarkable performance of the U.S. utility industry has been made possible by the technology base developed by R&D programs conducted or supported by federal and state governments, the Electric Power Research Institute (EPRI), individual electric utilities, electric equipment manufacturers, research institutes, and universities. The contribution of universities is especially important because universities are the means of educating the engineers and managers who are crucial to operating the utility systems and to the R&D performed by all participants.

To ensure the growth of the electric utility industry to meet the nation's needs old facilities must be replaced and new ones built. This growth requires continuously improved technologies and better capabilities to manage them.

During the period immediately after World War II, the rapid growth of loads provided strong incentives for utilities and equipment manufacturers to invest in R&D leading to improved products for an expanding U.S. electric power market. The results of these efforts satisfactorily addressed the nation's needs during nearly three decades of remarkable growth.

However, in the wake of the oil embargo imposed by the Organization of Petroleum Exporting Countries (OPEC), dramatically higher energy prices attended by other economic trends such as the shift to less energy-intensive industries have slowed load growth (Marlay, 1984). Whereas the projected and realized annual load increases were about 7 percent through the 1960s and early 1970s, the projected load increases for planning have become a more modest 2 to 3 percent in the 1980s (NERC, 1984). Table 1-1 shows that, while load growth has continued, the rate at which load has grown has declined.

The Response of Industry to Market Conditions

Manufacturers

As a result of a less than robust market, equipment manufacturers are now focusing their limited R&D on efforts either to reduce manufacturing costs or to improve the performance of existing technology for an equipment-replacement market. Long-term new-process or technology R&D is being neglected because market expectations are inadequate (Gerber, 1985a,b). Such a short-term focus creates the risk of eroding a large fraction of the base of U.S. electric system R&D. In an environment in which technical advancement is pursued only when justified by immediate market considerations, standardization of existing technology rather than innovation of product lines dominates. Major innovative technological improvements in electric power systems needed to increase energy efficiency, improve reliability, and enhance service in the long term are for the most part being neglected by U.S. equipment manufacturers, who are thereby leaving the field open to government-supported companies in Japan and Europe (Department of Commerce, 1985; Holden, 1980).

Table 1-1 Growth Indicators of the Electric Utility Industry, Selected Years, 1960-1983

Electric Utility Market Indicator	1960	1970	1975	1980	1983
Energy production					
(billion kWh)	753	1532	1918	2286	2310
Percent change		103.5	25.2	19.2	1.05
Average percent change		10.4	5.04	3.84	0.35
Installed capacity					
(gigawatts)	188	342	508	614	658
Percent change		81.9	48.5	20.8	7.2
Average percent change		8.2	9.7	4.2	2.4
Summer peak load					
(gigawatts)	133	275	357	427	415
Percent change		99.3	29.8	19.6	-2.8
Average percent change		9.9	6.0	3.9	-1.4

Source: Bureau of the Census, 1985, tables 971, 972.

Utilities

Decisions and policies of regulatory agencies often have the effect of discouraging investment by electric utilities in innovative technologies. State regulators are often reluctant to allow utilities to recover investments in innovative experimental technologies through increases in the rate base. As a result the electric utility industry has not been investing in its own technical future at a rate sufficient to keep pace with the potential benefits of innovative technologies (EPRI, 1984b; March, et al., 1981; Gerber, 1985a; NRC, 1985b, Gerber). In fact the electric utility industry has been spending substantially less than one percent (0.65 percent of sales) of revenues on R&D, which is about one-third of that for industry in general (EPRI, 1980). This is low not only with respect to other industries but also with respect to the R&D needs of electric systems. One expects the regulatory climate to act as a brake on electric utility R&D spending because of an inherent conservatism on the part of the local regulatory agencies, which respond to rate-payers' perceived reluctance to share the costs and risks of new technologies. Nevertheless industry spokesmen advocate that the industry itself spend much more on R&D. "The resources now being devoted are inadequate. The industry is barely meeting its current technology challenges. As a high-technology industry, it is not doing enough to pave the way to a solid future. This is particularly true in areas of advanced supply technology, end-use technology, exploratory research, and environmental assessment and control" (EPRI 1984b).

Other factors constraining electric utility R&D expenditures include the general business climate, interest rates, debt-equity ratios, and other factors related to the immediate financial health of the industry. In addition there are research topics related to national defense and public safety that are properly the responsibility of the federal government rather than of industry.

The result of all these factors has been to minimize those investments in R&D by the utility and technology supply industry that are necessary to meet long-term technical needs and ultimately to impose social costs on the nation. In the past, adequate investment in long-term R&D prevented such problems. For example, "the industry might have settled many years ago on the well-established 138 kilovolt (kv) transmission technology as the maximum transmission voltage rather than pushing the technology forward to 345kv and 765kv. The countryside would now be criss-crossed with a great many more transmission towers, and line losses would be significantly higher" (Gerber, 1985a). Other examples relating to thermal efficiency, environmental impacts, reliability, and safety could be cited. As a result of these recent trends, utilities have focused their limited R&D funds on efforts to reduce production costs or to improve the performance of existing technology for replacing older and less efficient equipment.

It is useful to examine the utility industry's R&D effort. Approximately half of the current $500 million industry R&D effort is expended through the Electric Power Research Institute (EPRI) with funds contributed by member utilities. Individual utilities, such as the American Electric Power Service Corporation (which alone has spent $58.2 million on energy R&D in the last six years), Southern California Edison, Florida Power and Light, and others, expend the other half. While EPRI has a longer-term R&D orientation than its individual members, it emphasizes projects that will prove useful to its members within the "short term," which it defines as the next ten years. EPRI's 1985 R&D expenditures in six fields are shown in Table 1-2.

Within the field of electrical systems R&D, EPRI's 1985 expenditures fall into three areas: transmission and power systems, which are located in EPRI's Electric Systems Division, and biological effects of electric fields, which is located in its Energy Analysis and Environment Division (EPRI, 1985). These three areas roughly correspond to DOE's three major R&D program areas in its Office of Electric Energy Systems: systems technology, reliability, and electric field effects, respectively. These EPRI expenditures are summarized in Table 1-3.

In general the EPRI program, as defined by its five-year plan, addresses the short-term operational needs of the industry. For example, the $6.3 million for research on overhead transmission lines mainly includes such practical short-term goals as improved structural design, better construction and maintenance, and more complete test facilities. Long-term innovative research on superconducting cables, for instance, is less than one-fifth the cost of the underground transmission program and receives less than $800,000.

CONCLUSION

Despite declining rates of industry growth, long-term needs must be addressed in order to ensure that the electric energy system can effectively and economically meet the nation's needs for reliable electricity beyond the year 2000. These needs go well beyond modest improvements in conventional technologies. They extend to the need for major innovative technological improvements needed to greatly increase energy efficiency, improve reliability, enhance service, and maintain technological competitiveness in world markets. In addition there are specific needs related to environmental effects of electric and magnetic fields that require a government role for credibility, and research needs related to the role of the power network in a larger strategy of national defense, which clearly requires federal leadership.

EPRI's R&D plans provide a very valuable frame of reference for power industry short-term (up to 10 years) R&D efforts. The definition of these efforts can help DOE structure its longer-term R&D portfolio, avoid duplication of effort, and complement industry efforts. Indeed,

Table 1-2 Electric Power Research Institute Overall R&D Expenditures, 1985

R&D Area	Millions of Dollars
Nuclear power	61.0
Coal combustion power	58.0
Electrical systems	42.0
Energy analysis and environment	35.0
Advanced power systems	35.0
Energy management and utilization	32.8
Total	263.8

Source: EPRI, 1985.

Table 1-3 EPRI Electric Systems Division 1985 Expenditures

R&D Area	Millions of Dollars
Overhead transmission lines	6.3
Underground transmission	4.4
Transmission Substations	10.6
Transmission Subtotal	21.3
Power system planning and operations	7.2
Distribution	9.0
Plant electrical systems and equipment	4.5
Power Systems Subtotal	20.7
Division total	42.0
Biological effects of electric fields	1.5
Total Electric Energy Sysmtes	43.5

Source: EPRI, 1985.

by maintaining the existing close collaboration in their R&D planning, EPRI and DOE can help ensure that their combined limited resources are used as effectively as possible.

Even so it is the Committee's view that the current combined budgets of the industry and DOE do not adequately support the nation's need for electric energy systems R&D. There is a need both to increase R&D support and to maintain a consistent level of funding to ensure stability of R&D programs. The following chapters review general EES program needs and EES R&D plans. They also provide the Committee's views on which programs merit continued or increased levels of support.

2

SYSTEMS TECHNOLOGY

BACKGROUND

Systems technology deals with the wide range of concepts, specialized materials, products, and components on which the successful operation of electric utility systems depends. As the electric utility industry experiences increasingly complex planning and engineering problems and as new technological opportunities are presented, there is a continuing need for research and development (R&D) in the various systems technology areas. This includes research in which the results are incremental improvements to existing systems as well as that in which the results may represent an entirely different technology based on scientific advances such as superconductors. Issues in systems technology are described in terms of components and materials research, alternative delivery systems, and load leveling and energy management.

Components and Materials Research

Materials

Materials form the basic building blocks for the electric industry. Materials with very precise characteristics are required as dielectrics (nonconductors, including insulation), conductors, mechanical support, and heat transfer media in generators, transmission lines, transformers, capacitors, circuit breakers, sensors, controls, and other components of the electric system. Materials must meet a variety of strict specifications for electric, mechanical, and thermal performance: reliability, resistance to environmental stress, resistance to decay or combustion, and finally cost.

Research is needed on materials to improve the efficiency of the electric components to allow them to function more efficiently under the high voltages used in utility networks and to be environmentally safe under normal use or during emergency events. In particular, improved testing techniques are needed to measure the effects of aging, such as loss of function (electric, mechanical, structural), and chemical and physical changes under normal wear and under emergencies such as fire. There is a corresponding need to understand the mechanisms that govern material behavior, such as aging, chemical breakdown, charging and discharging, and interfacial phenomena. For example, research on dielectric (that is, insulating) materials may result in such benefits to transformers as improved voltage grading, improved reliability, ability to sustain higher loads, lower energy losses, and reduced damage to the environment in the event of failure (NRC, 1985b, Dale).

Superconducting materials are the opposite of dielectric materials because they permit the flow of electric energy at close to zero resistance and thus cause only minor energy losses. The successful development of superconducting electric generators would result in much smaller sizes for a given rating and better electric characteristics, which would lead to energy savings and to improved stability of the overall power delivery system. Superconducting materials may also have application in power transmission, energy storage, transformers, and fault-current limiters.

Electric Components

Electric components provide the physical control functions that make the operation of power transmission and distribution systems possible. Here are some summary facts about key components, with size or capacity exceeding 115 kV and ranging up to 765 kv, that illustrate the market for technological improvements (see NRC, 1985b, Damrell).

- Power transformers: 26,000 units in 1983 with total capacity of 2300 gigavolt-amperes (GVA). By 1990, 30,000 are projected with total capacity of 2900 GVA.
- Circuit breakers: 40,000 units in 1983 with projection by 1990 of 45,000.
- Capacitors: 24,000 series and 37,000 shunt capacitors in 1983 with 29,000 and 50,000 respectively projected by 1990.

In addition to the above there are other important electric components in increasing use: protective relays, meters, switches communication systems, and information storage and retrieval systems.

Continuing R&D efforts are needed to improve the quality of electric components in order to enhance both system reliability and energy efficiency. For example, there is a need to predict when a transformer is approaching failure in relation to its operating conditions. There is a need for higher interrupting capacity and faster circuit breakers together with techniques to locate and analyze faults in the network. There is a need to reduce the space requirements of capacitors while increasing the capacity and a corresponding need to develop liquid-free units. Finally, there is a need to improve network control methods taking advantage of new opportunities in communication and computer technologies (NRC, 1985b, Damrell).

An important common component in most advanced power conditioning and control (PCC) systems is the switching device that delivers the electric power, usually a power semiconductor. Improvements in manufacturing techniques, operating characteristics, and circuit design have reduced and will continue to reduce the cost of the power semiconductors and the cost per watt of service.

The expanded application of PCC systems into such areas as high-voltage direct current (HVDC) transmission, load leveling and energy storage, superconducting magnetic energy storage, adjustable speed drives, retrofitting of less efficient PCC systems, and increasing the power transfer capability of existing facilities and rights of way all point toward improved system reliability and energy efficiency. This is consistent with the advances being made in microprocessors and other large-scale integrated circuits.

While the potential benefits of power semiconductors appear attractive, manufacturers and users have concentrated their design efforts on the load-device interface, with little attention being devoted to the utility interface. Harmonic voltage and/or currents, low power factor of operation, and electromagnetic interference (EMI) generated by PCC systems can lead to a degradation in the present quality of grid power. Guidelines defining tolerable levels of harmonic content and EMI have yet to be established.

Alternate Delivery Systems

Superconductor Technology

Superconductors today need an operating environment within a few degrees of absolute zero. Liquid helium is typically used to provide this environment, and the necessity to maintain such a low temperature creates a variety of engineering, cost, and energy loss problems. Revolutionary changes are required in superconductor technologies. New materials that will superconduct at higher (liquid nitrogen) temperatures and at the same time possess other properties that permit their effective engineering installation need to be developed.

There is need for research well beyond developing new materials. The incorporation of superconductors into devices requires the development of new technological systems. These materials require careful thermal isolation from the ambient system surrounding them and leading to their walls, and vacuum spaces further isolating the material. Devices in electric energy systems are subjected to unusual electromagnetic stresses and resulting mechanical forces, which require robust supporting structures. The design of systems that meet the need for both thermal isolation and electromagnetic/mechanical robustness is a new and developing field. Long-term support to design and test such structures and to gain experience with them is required to meet the future needs of the utility industry (NRC, 1985b, Smith).

High-Voltage Direct Current (HVDC) Power Transmission

HVDC systems are a comparatively recent addition to the North American interconnected bulk power transmission network. Those presently operating, under construction, or planned are mainly in the western states and along the New England-Canadian border, with additional lines in eastern Texas and Florida.

The advantages of HVDC include its ability to provide a nonsynchronous connection and better controllability and availability than alternating current (AC) transmission lines. A nonsynchronous connection is a critical property because many power systems, such as those in Quebec and New England, cannot be readily connected directly with AC transmission lines because of a stability problem. The connection of such systems through HVDC lines allows less expensive surplus electric energy to be transmitted to regions that need it. This electricity transfer is an important contribution to energy conservation, involving for example the substitution of hydroelectric power from Canada for oil-fired electric generation in the United States.

However, HVDC has disadvantages that must be addressed by R&D. The reactive power requirements, for instance, are too large, being about 50 percent of the megawatt (MW) power rating at each converter station. The DC conversion equipment also generates harmonics that must be filtered out. Finally, the applications are constrained by the lack of commercial circuit breakers. This limits HVDC systems to point-to-point application within AC networks and prevents the development of DC networks.

Research is required to develop satisfactory circuit breakers and forced commutation circuits. Advanced system studies for multiterminal DC systems and for the coordinated operation of AC/DC systems are also needed. Overall system efficiency can be improved by limiting the inadvertent flows which are characteristic of AC systems. System security can be enhanced by advances in dynamic control of active and reactive power systems. Further opportunities for increased efficiency and for energy conservation lie in investigating the use of DC for urban systems, which presently rely on underground cables for transmission. Such AC cables are much more sensitive to the effects of inadvertent power flows (NRC, 1985b, Long).

Load Leveling and Energy Management

Electric utility generating equipment has three general classifications: baseload, intermediate load, and peak load. Baseload equipment typically consists of very large (1000 MW) coal-fired or nuclear power plants, which are designed to run continuously. Baseload equipment maximizes economy of scale and provides the lowest operating unit cost per kWh. Intermediate load equipment typically consists of smaller units (100-500 MW) that operate from 6 to 18 hours a day by tracking the hour-to-hour variation in user demand on the system. Of lower capital cost than baseload equipment, intermediate load equipment has a somewhat higher unit operating cost. Such equipment typically uses fuel oil, but coal-fired plants are also employed. Finally, peak load units are small (50 MW and less) very flexible units with very rapid startup and shutdown responses. They have the highest unit operating cost, typically a factor of five to ten more than the baseload plants, and their operation has the greatest effect on fuel adjustment charges in a customer's electric bill. Economical operation of the system of electric generating equipment clearly favors maximizing the use of baseload equipment and minimizing the use of peaking equipment. Therefore utilities are constantly evaluating methods to make the load as "level" as possible. Because fuel costs have increased radically since 1973, the economics of load leveling have become correspondingly more attractive.

Two major strategies exist for load leveling. One is to use energy storage. The commercially available and widely used method for doing this is pumped-storage hydro, in which water is pumped to a holding reservoir at periods of slack demand (thus increasing the load during off-peak periods when the cost of energy is at a minimum) and is released to generate hydroelectric power during the period of maximum demand (thereby displacing highest-cost generation during the peak-load periods). Other energy storage methods that have been considered include using compressed air, batteries, and superconducting magnetic devices. Unfortunately these options are not commercially viable at today's level of technological development. There is a critical need for continued research and development in this area.

The other option for load management, demand management, involves the selective control of the consumer's use of energy (EPRI, 1984a). For example, in return for reduced electric rates, customers may agree to have major appliances such as air conditioners turned on and off by the utility to reduce peak load on the system. Research in this area is required in order to develop new hardware systems for sensing the load as distributed over the system and for sending out the complex of control signals required to modify the demand. Parallel research is needed for the software that provides the logic on analyzing enormous amounts of real-time data and making operational decisions (NRC, 1985b, Kalhammer and Yau).

COMMITTEE FINDINGS

Research work in systems technology, if successful, may result in commercially useful products and processes. Therefore to the extent possible, it is expected that the private sector will take initiatives, motivated by the expectation of a profitable return. However, as discussed in chapter 1, there are circumstances in which research, if successful, would produce major national economic benefits, but the private sector, for various reasons, may not be in a position to make the necessary investment on its own.

In reviewing the EES portfolio of systems technology projects (DOE, 1984a,b,c,d; ORNL, 1984), the Committee finds that in general the program is supporting research undertakings that meet the criteria for federal support: they have major potential payoffs, but the time until payoff is too long to attract sufficient private sector investment, particularly given the current business conditions of the utility industry. The Committee also finds that the various research topics are in general appropriate and are properly designed. The Committee believes there is a compelling national need for research on advanced systems technology to enhance the efficiency and reliability of future electric systems and to maintain U.S. technical leadership in areas that relate to long-term energy security.

The Committee's detailed comments and suggestions for improving the overall portfolio of research projects are provided in Table 2-1.

The Committee recommends that future presentation of the systems technology program be in terms of three major subprograms: components and materials, alternative delivery systems, and load leveling and energy management. This will help in communicating the program to DOE management and to policy makers. Table 2-1 is organized accordingly.

While the Committee does not set priorities within the EES list of projects or its own project suggestions, it has recommended that one of the existing projects, the Hawaii Underwater Cable, be phased out, as indicated on Table 2-1. In a later section, Table 5-1 shows that the EES has given this project a low priority, 18th in a list of 20 discretionary projects. The Committee feels that the limited federal funds available for EES research are better applied to other projects that more clearly meet the criteria for federal support.

The Committee also recommends that procedures be in place to ensure that the research is not likely to be duplicated by one of the several other federally funded research programs. This has particular importance in the materials area. In addition there must be an awareness of the work being sponsored by both EPRI and by manufacturers.

Table 2-1 Systems Technology Research Recommendations

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Components and materials			
New materials	1.0	Improve fundamental electric, magnetic, mechanical, and optical properties	Evaluate new concepts in transformer cooling; DC circuit breakers and high-voltage high-capacity AC circuit breakers
			Identify currently used processes and dielectric magnetic core and conductor materials that can benefit from improvements
Electric insulating materials	1.0	Develop superior liquid, solid, and gaseous dielectric materials	Develop a fundamental understanding of aging and associated failure mechanisms of dielectric materials
			Investigate fundamental mechanisms and interfacial phenomena of dielectric materials--liquid, solid, and gaseous
Power semiconductor concepts	1.5	Develop crystalline and amorphous semi conductor materials and other materials concepts	- - -

Table 2-1 Systems Technology Research Recommendations (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Alternative delivery systems			
Superconducting power delivery	1.0	Develop advanced cost effective cryogenic cable insulation	Continue R&D on superconducting transmission lines
Superconducting technology	1.0	Develop power equipment concepts. Investigate underground AC cables, advanced concept synchronous generation, and cryogenic refrigeration	- - -
High voltage direct current	3.0	Advance the state of the art to achieve higher efficiency at lower cost	Perform research in HVDC to include forced commutation circuits (new bridge configurations, new power semiconductors), system studies (multiterminal lines, urban applications coordinated AC/DC systems)
Automation and processing concepts	2.0	Perform automation and control experiments, communications, protocol studies, and applications of fiber optics	Develop ways to retrofit existing facilities for higher capacity and with less impact on the environment.
			Investigate dispersed generation--cogeneration, windfarms, low-head hydro, and other growing dispersed technologies

Table 2-1 Systems Technology Research Recommendations (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Decision analysis and control	0.5	Develop expert computer systems for information processing to assist decision making in operations and in expansion planning	- - -
Hawaii Deepwater cable	5.8	Technical and economic feasibility study of Hawaiian Islands submarine DC power cable	Phase out the Hawaii Deepwater cable project
Load leveling and energy management			
BEST/load leveling	0.8	Test advanced batteries under realistic utility operating conditions, in order to prove prototype system concepts	Participate in a coordinated national program of advanced compressed air energy storage Perform exploratory R&D for alternate electrochemical and chemical systems for load leveling and energy storage

Table 2-1 Systems Technology Research Recommendations (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and Recommended Topics
Advanced battery systems integration	1.0	Develop prototype design concepts for utility load leveling applications to be tested at BEST facility	Explore technical and economic prospects for superconducting magnetic energy storage
			Explore new techniques for cool storage
			Identify the benefits of integrated planning and operation for supply-side and demand-side energy management systems.

3

RELIABILITY

BACKGROUND

Conventional Reliability Issues

Reliability pertains to the availability of service to the customer. Electric systems in the United States are very reliable. Recent typical experience is 1.65 outage events per year with an average duration of 68 minutes (NRC, 1985b, Ringlee). Almost all of these events were caused by malfunctions in the local distribution system. In many cases they were weather-related (high winds, ice, lightning, and the like). The number of customers interrupted in each incident most often ranges from a few to a few hundred, and service is usually restored quickly by emergency crews.

Interruptions in the bulk power system, on the other hand, have been quite different in extent, frequency, and effect. They usually affected large areas and many customers, lasted for a long time (a day to several days), and had widespread social and economic impact. Fortunately they were extremely infrequent. The principal technical defenses against these events have been a strong transmission system, extra on-line generation (spinning reserve), quick-start generation, the ability to shed load quickly, and early detection and response to imminent exposure to such an event.

While much has been done in this field, such as the installation of highly sophisticated computers and control and detection systems, further research and development is needed (NRC, 1985b, Thomas). Continuing major innovative research is required to:

- o Exploit opportunities for upgrading system performance by more advanced and sophisticated system technology operation and planning methods (NRC, 1985b, Kirshner).
- o Reduce vulnerabilities to major unanticipated contingencies by developing advanced methods of flexible automated emergency control and restoration.
- o Improve the understanding of the economic and social forces affecting growth and development of the electric power industry (NRC, 1985b, Gerber).

Accordingly, it is essential to maintain researchers versed in both power and systems technologies required to put into practice these advanced techniques.

National Defense Issues: Electromagnetic Pulse

A nuclear strike against the United States might be preceded by the detonation of one or more nuclear devices at 50 km above the center of the country. Such a strike could generate a powerful electromagnetic pulse (EMP) that would disrupt all the nation's unhardened telecommunications and electric power systems. As a result, U.S. strategic restrike capability among other things would be impaired and all unhardened computer systems either destroyed or seriously damaged. How to maintain some level of reliability in the wake of such a threat is the objective of this research.

Characteristics of EMP

A high-altitude EMP generated at 50 km above the surface is not usually accompanied by other effects of nuclear weapons (depending on the size of the weapon) such as heat and shock waves. In the case of a smaller weapon the gamma radiation from the burst interacts with the atmosphere at a height of 20 to 40 km. High-energy electrons are created in a huge pancake-shaped zone, the area of which is limited only by the height of the burst and the curvature of the earth's surface. In the presence of the earth's magnetic field, electrons spiral around the earth's geomagnetic field lines (see NRC, 1984, for more detailed discussion). The acceleration of the electrons along these curved paths results in a transverse current that acts as a phased magnetic dipole array. These transverse currents are the primary source of the EMP fields (NRC, 1985b, Singaraju). The transient EMP fields are characterized by a high power density with a fast rise time measured in 10 billionths of a second (nanoseconds). This fast rise time results in a wide excitation bandwidth with significant energy distributed over a broad range of the electromagnetic spectrum, but the bulk of the EMP energy lies within the radio frequency range.

Electric conductors exposed to an EMP field act as inadvertent antennas by receiving energy from the EMP illumination. All unhardened power lines, phone lines, unshielded control cables, and antennas experience induced surges with amplitudes similar to those of average lightning strikes. These surges electrically stress the line and equipment insulation and also couple some energy to potentially vulnerable solid state components in instrumentation and control (computers), which are subject to burn out.

Unknown Factors

It will be necessary to characterize the surges induced on electric power system transmission and distribution lines and the effects of those surges on system components in order to analyze the impact of EMP on the operation of electric power systems. While techniques to model EMP energy and induced transients coupled to antennas, shielded cables, phone lines, cables within partially shielded enclosures, and so forth have been developed under other federal programs, a substantial research effort will be needed for the application of these and other EMP assessment techniques and methods of statistical analyses to complex electric power systems and components.

The potential vulnerability of U.S. electric power systems to EMP surges is recognized. At present there are no operation and control strategies in effect in the United States to mitigate the effects of EMP on the electric power system (NRC, 1985b, Cikotas). Furthermore, because the exact nature of the threat and possibilities for mitigation are not well understood, a theoretical foundation is necessary, but does not now exist, to understand how electric power systems respond when subjected to EMP (Manweiler, 1975). Additional discussion of the problems of estimating vulnerability and formulating defenses is provided by a recent National Research Council report (NRC, 1984).

Willingness of Private Industry to Conduct EMP Research

The federal government is responsible for national security. The electric utility industry, in cooperation with federal and state authorities, is responsible for meeting the nation's energy needs and for cooperating fully with federal agencies in matters of national security. However, without a better understanding of the problem, its relative importance in times of national stress, or the cost of various mitigating measures, it is difficult for industry to justify a high priority for research on EMP effects. Therefore it is unlikely that private industry would conduct EMP research using its own funds.

COMMITTEE FINDINGS

Research in conventional reliability, if successful, may produce commercially useful results because electric energy providers will purchase technology in order to benefit their customers with enhanced systems reliability. As electric power systems become increasingly complex and employ more advanced systems technology, there is a corresponding need for more advanced methods of maintaining reliability. The appropriate cost of a given level of reliability is a technical and market issue for the electric utility industry and its customers as represented by the various regulatory commissions. In evaluating programs for federal support, the Committee applies the same criteria as in the case of systems technology.

Research in the area of EMP, if successful, will enhance national defense, but will not produce commercially useful results. Accordingly, if the government does not fund or otherwise mandate the research, it will not be done.

In general the Committee finds the EES reliability projects consistent with needs recognized by industry and with federal criteria for support. No major exception is taken to the EES plan (DOE, 1984b). The Committee's detailed comments on the EES portfolio are provided on Table 3-1, and additional discussion follows.

Conventional Reliability Issues

It is important to have an electric power network that will have control of all electric energy sources, ensure continuity of essential services during local, regional, and national emergencies, and encourage regional energy exchange. While the present system is extremely reliable, the economic and social costs of system failures, especially widespread failures like the blackout in the Northeast in 1965, are very high. The costs include such effects as the inability of government to function effectively that go far beyond the minor inconvenience of the occasional interruption of power for an hour or so.

In formulating its recommendations the Committee took into account the portfolio of industry-based research on reliability funded by the Electric Power Research Institute (EPRI, 1985b). In general the EES portfolio addresses longer-term, more technically innovative topics, while EPRI emphasizes projects likely to produce commercially useful results within a short term (less than 10 years).

National Defense Issues: Electromagnetic Pulse (EMP)

Needs in research on EMP include defining and characterizing the exact nature of the threat, developing technology to protect vulnerable components of the electric power delivery system, and defining strategies to resume limited or full power operations as soon as possible after an EMP event. EMP research in general is the responsibility of the Department of Defense. To the extent that the research directly applies to the operation of electric power systems, the DOE should be the bridge between DOD and the electric utility industry. The thrust of the DOE effort in EMP research should be continued but at a greater level of funding and staffing. DOD can support these EES efforts by continuing to make available to DOE such data as is important for assessing effects.

Table 3-1 Recommendations on Reliability Research

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and and Recommended Topics
Conventional reliability research			
Normal/emergency operating concepts	1.6	Develop methods, strategies, and concepts for system operations by using advancead microcomputer technologies, particularly for abnormal operations	Some of the issues in new bulk power transmission facilities in need of resolution include predicting the risks and costs of widespread interruptions and assigning values to transfer capability which take into consideration reserves and load diversity benefits during strategic emergencies
Failure mechanisms	0.4	Develop a fundamental understanding of the failure mechanisms due to the aging of dielectric insulating materials used in cables, capacitors, transformers, motors, and generators	Given the key roles of security and integrity that protection and control systems play in power systems, incremental cost/benefit assessments are needed to evaluate the economic merits of improving the security and dependability of these systems; and to reducing, the risks of line failure because of lighting, fault clearing, or switching surge
Computeraided control	0.3	Improve the ability to measure the dynamic changes in electric power systems in real time	Reliability R&D should emphasize control strategies for limiting the area of outage, for making early detection, and for restoring power

Table 3-1 Recommendations on Reliability Research (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and and Recommended Topics
		in order to expand the use of microprocessors in the control and protective processes	rapidly. There should be a continued strong effort to develop computer models which can simulate operation of very large integrated systems under a great variety of stresses
			Opportunities exist for increasing power transfer capability of existing facilities and rights of way, of mitigating the environmental impacts, and of minimizing land or space use to penetrate dense load areas.
			Review the philosophy of continentwide synchronous systems
			The cost and reliability effectiveness of asynchronous interconnection of regions and power pools should be investigated
HVDC control/ protection	0.5	Verify and enhance control concepts	An assessment should be made to evaluate the economic merits of control capabilities for rapid reconfiguration, re-energization, and restoration as opposed to reducing the risks of failures in the bulk power supply system

Table 3-1 Recommendations on Reliability Research (continued)

EES Proposed Topic	EES FY86 Proposed Budget ($ million)	EES Topic Description	Committee Comments and and Recommended Topics
National defense issues/EMP			
Electromagnetic pulse analysis	3.0	Develop analytical and modeling techniques to determine magnitude of EMP effects on electric energy systems. Investigate protection, control, and operating strategies to mitigate those effects	Develop scientific and improved statistical models for representing the the influence of EMP on electric power systems Develop state of the art analytical methods for assessing the effects of EMP on electric power systems to EMP effects
Electromagnetic pulse impact mitigation	1.5	Develop options on how to harden the electric power network or to suppress the EMP transient	Develop and evaluate technologies and integration techniques designed to minimize the influence of EMP on electric power systemes Provide information and recommendations for electric power structural and operational requirements when subjected to EMP disturbances

Because of the national security implications of EMP research, DOE would be in a better position than the electric utility industry to work with classified documents. EPRI can also assist the government in such EMP research as pertains to public utility systems by characterizing systems, gathering data, and disseminating information. DOE should continue to direct its efforts toward developing technologies, systems, and information that will enable electric utility systems to provide power to essential loads such as military installations and critical industries, reduce damage to the overall power system, and minimize the duration of power outages for the public. To achieve these goals the Committee recommends that EES pursue the specific technical objectives indicated in Table 4-1. The technologies and systems should consider analytical and statistical modeling techniques, assessment methodologies, protective hardware, and special operating and control strategies.

4

SAFETY: ELECTRIC AND MAGNETIC FIELDS (EMF)

BACKGROUND

Human beings are exposed to electric and magnetic fields in the natural environment and from man-made sources such as radio and television transmission, home appliances, and computers. The particular focus in this chapter is on EMF at the frequencies and voltages used for the transmission and distribution of electricity, particularly at the higher voltages. In building and operating transmission lines and such associated equipment as transformers, the utility is responsible for understanding the environmental impacts and for taking steps to ensure that no harm is caused to persons, property, or the environment. The impacts of EMF fields at the levels induced by transmission lines are not well understood. Unfortunately there is a wide body of conflicting literature alleging that the effects on biological systems of EMF at levels induced by transmission lines range from the nonexistent to the catastrophic (Electronics and Power, 1985; Norris, et al., 1985; Squires, 1985; Wertheimer and Leeper, 1982).

The physical effects of EMF induced by transmission lines include audible noise and radio and television interference. Certain types of pacemakers can be adversely affected by exposure to these fields. With respect to biological effects, it is known that bees in hives may experience physiological and behavioral problems in the presence of EMF fields and that cattle may experience small shocks from induced voltages picked up by ungrounded metallic objects (NRC, 1985b, Tenforde).

Numerous investigators have attempted to determine to what extent the electrical and magnetic environment produced by transmission of electrical energy poses a health hazard to living organisms (NRC, 1985b, Tenforde, Phillips). Effects on the nervous system have been convincingly demonstrated in laboratory animals. The effects include altered neuronal excitability, altered levels of certain hormones affecting circadian rythms, behavioral changes, and altered locomotor activity. It is not yet known whether these and other observed effects are caused by a direct interaction of the electric field with tissue or an indirect interaction, such as a physiological response caused by sensory perception of the fields by test animals (NRC, 1985b, Justesen and Smith). The nature of the physical mechanisms involved in field-induced effects is obscure and is one of the most important goals of current research.

Based on the evidence examined, including the papers presented at the Workshop, the Committee believes that much of the literature claiming that EMF is hazardous fails to meet such criteria for objective scientific research as proper experimental controls and replicability of results.

The public at large has a serious and legitimate concern for the safety of electric power facilities and does not have the information and the criteria to make scientific judgments on its own. The literature on biological testing for the full range of potential effects posed by EMF is incomplete, leaving many questions unanswered. As a result, persons and organizations who sincerely believe in the harmful scenarios can take legal action either to prevent or to slow down the construction of new transmission and distribution facilities on the grounds that harmlessness cannot be proved. These actions, if successful, can add significant costs to both the construction of new facilities and to the operation of the electric power system, and can prevent needed expansion to improve reliability and economy of service.

Unfortunately it is impossible to prove in an absolute sense that an environmental agent such as EMF has no harmful effects under any and all circumstances. However, it is possible to provide a baseline of highly qualified research, specifically designed with electric power systems in mind, that would increase the understanding of the phenomena and would contribute to higher confidence levels for planners and builders of transmission facilities. Some of this work is being done by EPRI ($15 million is to be spent between 1985 and 1989), but however high its scientific quality may be, it will of itself not be adequate. To begin with, there is the problem of policy credibility when a party at interest sponsors the research. In addition the level of funding is limited and cannot be expected to cover all relevant research problems. Thus additional effort is needed both to evaluate and confirm EPRI's efforts independently as well as to add to the total pool of original investigation.

COMMITTEE FINDINGS

Recommended Research Program

As indicated on Table 4-1, an EES-sponsored research program aimed at addressing potential health hazards of AC and DC transmission lines should include both a long-term basic research component and a short-term applied research component. The objective of the short-term component should be to provide an adequate basis for establishing

Table 4-1 Recommendations on Safety: Electric and Magentic Field Effects

EES Proposed Topic	EES FY86 Budget ($ million)	EES Topic Description	Committee Comments And Recommended Topics
Short-term program			
Biological research AC	3.3	Establish an obejctive scientific data base of electric field effects, their thresholds of occurance, and the biological mechanisms by which effects are produced	For both AC and DC, short-term basic research components should aim to establish exposure guidelines based on dose-response curves for biological effects Develop a dosimetric basis for extrapolation of results from animal studies to humans
		Begin a program to determine the impact magnetic fields on human and health safety	Epidemiological studies of program to transmission-line field effects should begin immediately
Long-term program			
Biological reserach DC	0.9	Establish an objective scientific data base of DC electric field effects, ions, their thresholds of occurance, the biological mechanisms, and risk potential to humans	For both AC and DC, long-term basic research should have the objective of determining the mechanisms of interaction between AC/DC electric and magnetic fields and biological tissue

reasonable exposure guidelines. This program should involve an intense effort focused on established effects and should be aimed at determining dose-response curves for biological effects. A second part of the program should be aimed at developing a dosimetric basis for extrapolating results from animal studies to equivalent exposures in humans. A third and final part of the short-term program should involve epidemiological research. Planning for a careful program of epidemiological studies of transmission-line field health effects should begin immediately because lack of data may impede new transmission-line projects.

The Committee envisions a short-term component funded at a level of $10 million a year and lasting approximately five years. This research should lead to agreement on an appropriate index for establishing exposure standards. It must be recognized that such a standard will require periodic review and revision as information becomes available about the mechanisms by which electric and magnetic fields alter biological functions.

The long-term basic research component of this program should have as its objective the determination of mechanisms between electric and magnetic fields and biological tissue. A firm understanding of these mechanisms of interaction is required for reliable extrapolation to humans of laboratory studies of field effects on animals.

The Committee envisions a long-term program funded at a level of approximately $2 million a year conducted over a period of ten or more years. The exact length of time necessary for the conduct of this basic research is difficult to estimate.

Experience in the study of the biological effects of ionizing radiation suggests that even after the mechanisms of interaction are known, additional research will be required to address questions about the hazards of chronic exposure to very low level fields.

Critique of DOE's Current EMF Efforts

If the combined program of basic and applied research is to have any impact on the question of biological effects of transmission-line fields, it is essential that funding and management of the program develop far greater stability than has existed in the past at DOE.

This research has frequently suffered from poor definition of priorities, unstable funding, lack of competition and peer-reviewed analysis of proposals, mediocre quality of investigators, inadequate dosimetry of fields, and lack of solid scientific approach to the questions requiring double-blinded exposures, dose-response studies for effects, and tests for reproducibility of results. The result is that the field is cluttered with reports drawing conclusions of questionable validity.

It is critical that the DOE program be directed by a staff that is knowledgeable about both the biological and engineering aspects of exposures to electric and magnetic fields. For the program to be competitive the investigators selected should be of the highest quality. A system of peer review for research proposals is necessary: lack of adequate peer review has contributed to the perception of the current program as limited and unimaginative. The tendency to fund current contractors whose special EMF effects capabilities may be less than desired for work in such new areas, while offering some advantages in administration of the program, severely limits its vitality and is certain to lead to ultimate failure in the adequate identification of the causes and extent of field effects on humans.

In the view of the Committee, the administration of these programs by DOE has been far below standard. This may not reflect on the persons currently responsible for administering the program, but rather the lack of specialized personnel, the instability of the funding, and other factors beyond their control.

Whatever the reasons, the result has been a program that has marginal credibility and may not have supported the most competent investigators. It is critical that this program be competitive and that contract awards be made by a peer review process on the basis only of the quality of the application and the ability of the applicant. For the program to be successful and to avoid the past difficulties, it is critical that it be directed by a staff that is knowledgeable about both the biological and engineering aspects of EMF exposure. This administrative group within DOE should be enlarged to include biologists as well as engineers.

Proper Place of the Program

While the Committee agrees on the need for a federal program of research to address issues of the safety of power transmission lines, it is not obvious where such a program should reside. The National Institutes of Health (NIH) are responsible for several programs concerned with health and human safety. However, they are not highly directed to the specific problems of the power industry and are unlikely to give the problems adequate priority. For this reason NIH is probably an inappropriate choice. Agencies with regulatory responsibility in areas including radiation and field effects (the Environmental Protection Agency and the National Institute of Occupational Safety and Health) should maintain a research program of sufficient breadth to permit intelligent exercise of that responsibility, but they cannot be expected to undertake the role of developing the specific scientific basis for regulation with respect to the electric power industry.

DOE is the most logical agency to assume responsibility for support of basic research necessary to establish exposure standards related to the electric supply system. DOE historically has assumed this responsibility and has in the past initiated a program of research on health effects of AC transmission-line electric fields. Although the nature of the program and the location of responsibility for it within the organization has changed many times over the years, DOE has remained and should remain the major funding organization for research into the health effects of transmission-line fields.

5

ELECTRIC ENERGY SYSTEMS PROGRAM IMPLEMENTATION

PROGRAM HISTORY

The Electric Energy Systems (EES) program at the Department of Energy (DOE) is the culmination of many years' efforts to execute the federal government's responsibilities in helping to meet the nation's electric energy R&D needs. It has its origin in 1970 with Department of the Interior (DOI) participation in the utility industry's Electric Research Council (ERC)* underground transmission R&D program (NRC, 1985b, Parry). This program was selected for federal support because it addressed a clearly definable need to decrease the ratio of underground to overhead transmission costs, variously estimated in 1970 at between 10 and 20 to 1, and because it addressed a growing concern about environmental quality. Another reason was to join federal support to ERC's largest and most comprehensive R&D effort in a pilot program in government-industry cooperation. At the same time, the government hoped that the program would stimulate industry interest in funding a broad spectrum of electric power systems research opportunities.

By the middle 1970s the federal program, with objectives well beyond underground transmission, had been moved to the Energy Research and Development Administration (ERDA). The program worked cooperatively and effectively with the Electric Power Research Institute (EPRI), which was formed in 1973 as the successor to the Electric Research Council. The program also provided research support for new ideas from both industry and academia.

*An organization of most of the investor-owned and non-investor-owned utilities, along with the Department of Interior.

When DOE was created, the EES program was incorporated in it. With initial high-level support the staff grew to 28 professionals who were nationally recognized for their competence throughout the utility, equipment, industry, and academic sectors. The staff generated interest in the program both in the United States and abroad. But this period of growth virtually ended by 1980. Indeed, during the 1980s the trend has reversed and the program has badly deteriorated. In many ways it has come to be treated as a stepchild of DOE. For example, the program has been moved from one organizational structure to another within DOE and predecessor agencies 8 times in 11 years. As recently as 1985 it was relocated again, this time to the Renewable Energy Division of the Office of Conservation and Renewable Energy. The current EES organizational structure is shown in Figure 5-1. With each move, its program has been modified, redirected, amputated, and implanted with special projects not related to a central purpose. Not surprisingly it has experienced a very high turnover among program managers and such heavy staff attrition that only three professionals remain. While dedicated and hard-working, this staff is clearly too small to carry out the program effectively.

Meanwhile program budgets have declined in each year, from $35 million in 1981 to about $20 million in 1985, as shown in Figure 5-2. Thus the program has failed to meet such key criteria for a successful R&D program as stability of funding and continuity of dedicated staff persons.

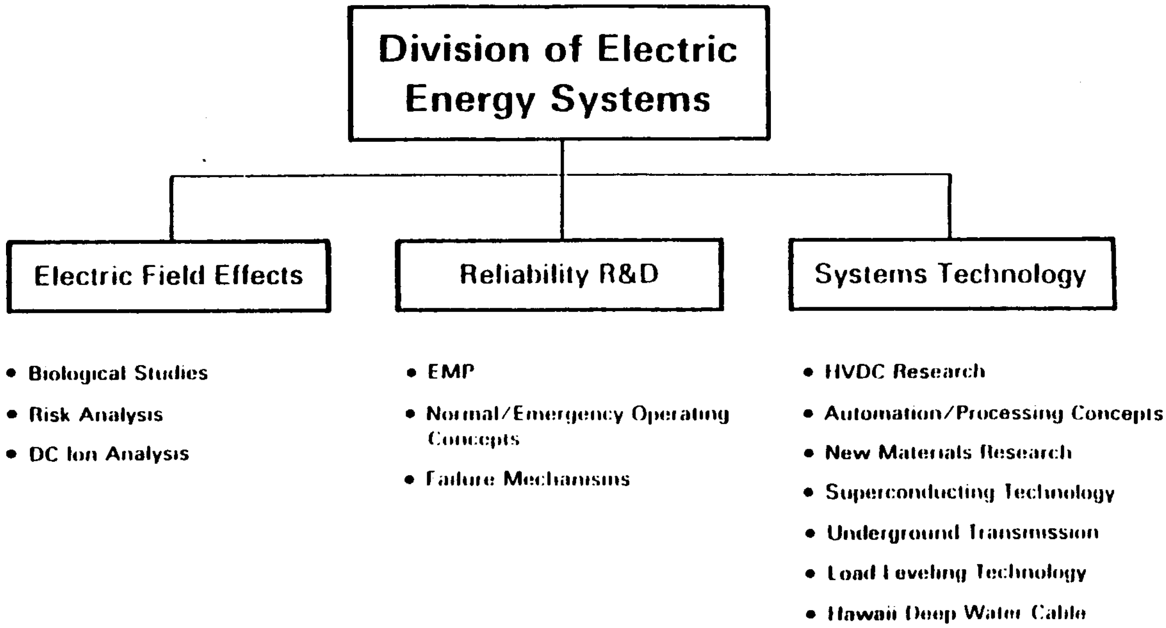
THE CURRENT DOE/EES PROGRAM

The current EES program divides its activities and allocates its resources among three primary research areas: electric field effects, reliability, and systems technology (see Figure 5-2). In 1985 the program expended approximately $11.4 million for electric field effects, $4.7 million for reliability, $4.2 million for systems technology, and only about $0.4 million for program management. Of the total expended on program R&D activities, 46.3 percent of the allocations were made to national and other laboratories, 38.2 percent to private sector research centers, and 13.7 percent to universities. The remaining 2.1 percent was for program direction.

For fiscal year 1986 DOE has proposed that $34.8 million be spent on the program's activities, as summarized in Table 5-1 (DOE, 1984b). This budget calls for a level of funding approaching that of 1981 in current dollars, but it falls considerably short in constant dollars (adjusted for inflation).

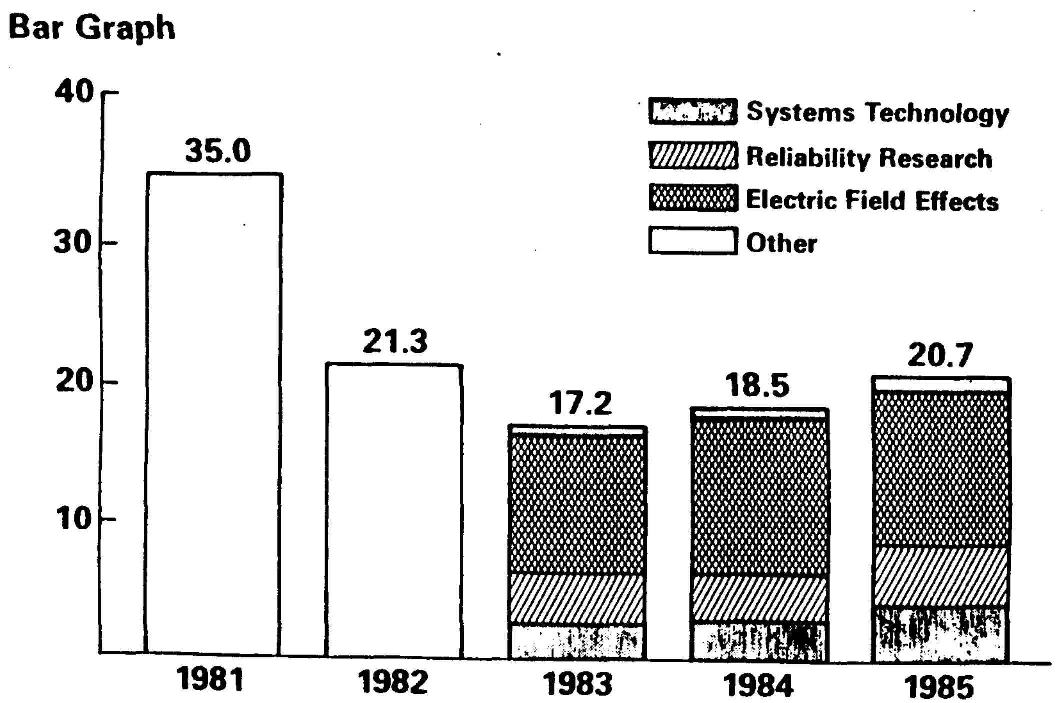
This is in sharp contrast to the $10 million finally requested by the administration in the president's budget for fiscal year 1986, to which an additional $2 million has been added by the respective appropriation committees in congress. An additional amount of approximately $8 million will be carried over from 1985 funds, but $6 million of this is dedicated to a single project, the Hawaii Deepwater Cable.

Figure 5-1 Organization of the Electric Energy Systems Program



SOURCE: DOE (1985).

FIGURE 5-2 Electric Energy Systems Budget History ($ In Millions)



SOURCE: DOE (1985).

Table 5-1 Projects and Priorities of DOE's Multiyear plan, FY 1986-1990

Priority	Title	Subprogram/ Major Activity Area	FY 1986 Level of Effort ($ millions)
Nondiscretionary activities			
A	Program direction		0.5
B	Technical concepts and management		1.8
C	Research assessments and technology transfer		1.2
D	Small business innovation research		0.2
E	Historical black college research		0.2
	Subtotal		3.9
Discretionary projects			
1	Biological research AC	Electric field effects	3.3
2	Electromagnetic pulse (EMP) impact analyses	Reliability R&D	3.0
3	Biological research DC	Electric field effects	0.9
4	Normal/emergency operating concepts	Reliability R&D	1.9

Table 5-1 (continued)

Priority	Title	Subprogram/ Major Activity Area	Fiscal Year 1986 Level of Effort ($ millions)
5	High-voltage direct current	Systems technology improved efficiency	3.0
6	New materials	Systems technology (improved efficiency)	1.0
7	Automation and processing concepts	Systems technology (improved economic performance)	2.0
8	Superconducting technology	Systems technology (improved efficiency)	1.0
9	Electric insulating materials (increment)	Systems technology (improved efficiency)	1.0
10	Superconducting power delivery research (increment)	Systems technology (improved efficiency)	1.0
11	Decision analysis and control (increment)	Systems technology (improved economic performance)	0.5
12	HVDC control/ protection (increment)	Reliability R&D	0.5
13	Failure mechanisms	Reliability R&D	0.4

Table 5-1 (continued)

Priority	Title	Subprogram/ Major Activity Area	Fiscal Year 1986 Level of Effort ($ millions)
14	Computer-aided control (increment)	Reliability R&D	0.3
15	Power semi-conductor concepts	Systems technology (improved efficiency)	1.5
16	Microprocessor-based simulation (increment)	Reliability R&D	0.5
17	BEST/load leveling	Systems technology (improved economic performance)	0.8
18	Hawaii deepwater cable	Systems technology (improved economic performance)	5.8
19	EMP impact mitigation (increment)	Reliability R&D	1.5
20	Advanced battery systems, systems integration (increment)	Systems technology (improved economic performance)	1.0
Subtotal			31.9
Total			34.8

SOURCE: DOE, 1984b.

Thus the EES will have about $20 million for fiscal year 1986, of which about $6 million is for a single project and $4 million is for nondiscretionary activities. This leaves only $10 million for all other EES R&D support, far short of the Committee's recommended level of support as discussed in the following section.

RECOMMENDED BUDGETARY SUPPORT

The Committee recommends that the EES program be supported by a budget of approximately $45 million annually. This recommendation is based on the requirements for a diversified R&D program related to national needs, and on the associated management and support functions required for EES to be an effective entity. It is also based on the Committee's views of an R&D portfolio in the national interest, as discussed in chapters 2, 3, and 4.

The Committee has not taken a position on how this budget should be allocated among projects nor on how these projects should be ranked in importance because this is the job of the EES management within DOE planning procedures. The Committee does, however, offer a general estimate as a point of departure for EES planning in Table 5-2, which compares the Committee's view with that of the EES-proposed budget for fiscal year 1986. The Committee makes the following observations:

- The Committee recommends a greatly increased level of effort in electric and magnetic fields, encompassing both short- and long-term research, as recommended in chapter 4.
- The Committee recommends that the nondiscretionary component be increased to accommodate additional staff persons, as recommended in the following section. This amount can include the public awareness program and the education program.
- The Committee concurs with the EES planned level of effort for systems technology. However, as discussed previously, the Committee suggests that EES reconsider the portfolio in the light of recommendations of chapter 2.
- The Committee concurs with the EES planned level of effort for electromagnetic pulse research.
- The Committee recommends a moderate increase in conventional reliability research in order to carry out the program recommendations of chapter 3.

Table 5-2 Proposed Budget for Electric Energy Systems, FY 1986

Category	Committee's Proposal ($ million)	EES FY 1986 Proposal ($ million)
Systems technology	18.5	18.6
Reliability		
Conventional	5.0	3.6
EMP	4.5	4.5
Safety	12.0	4.2
Nondiscretionary	5.0	3.9
Total	45.0	34.8

OTHER PROGRAM NEEDS

Additional Staff

The Committee has recommended an increase of about $1.1 million in nondiscretionary programs in order to support the additional professional personnel needed to manage the program adequately. As indicated in chapter 4, the additional personnel should have sufficient biological expertise to ensure the quality control necessary for a successful research program on biological effects.

Support for Graduate Training

The EES staff should make every effort to ensure that allocations to universities enhance opportunities for graduate student participation in electric energy systems research. Without expending additional funds, these efforts would encourage graduate students to consider careers as managers, scientists, or engineers in electric energy systems or related fields. The Committee believes that the EES R&D program must be concerned not only with long-term technical and management problems but also with the quality and training of engineers for careers as researchers, designers, operators, and managers. Involvement in reliability and some aspects of systems technology research is likely to influence a career choice in favor of the electric power industry. Work on materials, cryogenics, or animal experiments may not have such a direct result.

Public Information

As a part of its management responsibilities, the EES R&D program should also undertake efforts to make information about its program and R&D activities readily available. Program and R&D reports on relevant topics should be provided to DOE's Energy Information Administration, to other DOE and executive branch agencies and offices, to organizations involved in electric energy systems R&D, and to the general public.

Stability and Continuity

The long-term orientation of the EES R&D program requires that DOE management understand the importance of its long-term support. Budgetary and staff support are indispensable, but a commitment to a sustaining organizational environment is also important. Effective management at all levels of DOE, including effective two-way communication, is necessary to ensure an environment conducive to long-term, high-quality research and productive results. Given the frequency and the adverse effects of past relocations, reorganizations, reductions, and redirections of the EES program, DOE management should refrain from making sudden changes altogether and should hesitate to make major changes without ensuring that the resulting benefits substantially outweigh the costs. The recommended steps to increase program stability and continuity, like those to increase budgetary and personnel support, are intended to strengthen and revitalize an electric energy R&D program that is important to meeting the nation's energy needs.

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APPENDIX A

WORKSHOP ON
ELECTRIC ENERGY SYSTEMS RESEARCH

APRIL 24-26, 1985

NATIONAL ACADEMY OF SCIENCES
JOSEPH HENRY BUILDING, ROOM 451
2122 PENNSYLVANIA AVENUE, N.W.
WASHINGTON, D.C. 20418

A G E N D A

WEDNESDAY, APRIL 24, 1985

7:30 a.m. REGISTRATION

8:30 a.m. Welcoming Remarks
Dennis F. Miller, Executive Director
Energy Engineering Board

Andrew F. Corry, Electric Energy
Systems Committee Chairman

8:45 a.m.
- Keynote Address-Overview
  Craig Tedmon, General Electric

SESSION I: SYSTEM TECHNOLOGY

9:30 a.m.
- Materials
  Steinar Dale, Oak Ridge National Laboratory

10:15 a.m. B R E A K

10:30 a.m.
- Superconductors
  Joseph Smith, MIT

11:15 a.m.
- Total Systems Technology
  The Hawaiian Geothermal and Submarine Cable Project
  Richard O'Connell, Hawaiian Electric Company. [Paper presented by:]
  William A. Bonnett, HDWC Program Manager

WEDNESDAY, APRIL 24, 1985 (continued)

12:00 Noon	L U N C H	
	SESSION 2: SYSTEMS TECHNOLOGY AND RELIABILITY	
1:00 p.m.	•	HVDC Willis F. Long, (ASEA)
1:45 p.m.	•	Load Leveling Fritz Kalhammer, Electric Power Research Institute (EPRI)
2:30 p.m.	•	Electrical Components C. Bruce Damrell, Boston Edison
3:15 p.m.	B R E A K	
3:30 p.m.	•	EMP Effects Dr. Babu Singaraju, Air Force Labs/ Nuclear Technology Communications
4:15 p.m.	•	EMP Defenses Bronius Cikotas, Nuclear Defense Agency
6:00 p.m.	•	Cocktails before dinner at the Cosmos Club, 2121 Massachusetts Avenue, N.W., Washington, D.C.
7:00 p.m.	•	D I N N E R Guest Speakers: Benjamin Cooper and Robert Grundy, Staff Members, U.S. Senate Committee on Energy and Natural Resources TOPIC: Energy Policy Making: The View from Capitol Hill

THURSDAY, APRIL 25, 1985

	SESSION 3: RELIABILITY
8:30 a.m.	Introductory Remarks

THURSDAY, APRIL 25, 1985 (continued)

8:45 a.m.	•	Normal/Emergency Operations-Efficiency Abraham Gerber, National Economic Research Associates
9:30 a.m.	•	Normal/Emergency Operations-Economic Concepts Economic Trade Offs Daniel Kirshner, Environmental Defense Fund
10:15 a.m.		B R E A K
10:30 a.m.	•	Normal/Emergency Operations-Utility Needs and Experience Samuel C. Thomas, GPU Service Corporation, [Paper presented by:] J.D. Gassert, Director, Systems Operations
11:15 a.m.	•	Failure Mechanisms Robert Ringlee, Power Technologies, Inc.
12:00 Noon		L U N C H
		SESSION 4: ELECTROMAGNETIC FIELDS
	•	The Nature of Electromagnetic Fields Thomas S. Tenforde, Lawrence Berkeley Laboratory
1:45 p.m.	•	Electric Field Effects Richard O. Phillips, Environmental Protection Agency (EPA)
2:30 p.m.		B R E A K
2:45 p.m.	•	Magnetic Field Effects Robert Smith, Veterans Administration
3:30 p.m.	•	Research Perspectives Rene Males, EPRI

THURSDAY, APRIL 25, 1985 (continued)

4:15 p.m.	• Role of Federal Agencies Department of Energy - Martin Minthorn Environmental Protection Agency - Richard Phillips Veterans Administration - Robert Smith Federal Drug Administration - Moris L. Shore

FRIDAY, APRIL 26, 1985

SESSION 5: PANELS

8:00 a.m.	• PANEL ON SYSTEMS TECHNOLOGY
9:15 a.m.	B R E A K
9:30 a.m.	• PANEL ON RELIABILITY
10:45 a.m.	B R E A K
11:00 a.m.	• PANEL ON ELECTROMAGNETIC FIELDS
11:45 a.m.	B R E A K
12:00 NOON	WORKING LUNCH COMMITTEE MEETING (CLOSED SESSION)
5:00 p.m.	ADJOURNMENT

PANEL MEMBERS

Thomas Dy Liacco, Consultant, Dy Liacco Corporation

Nicholas Grant, Massachusetts Institute of Technology

Robert Lawrence, Westinghouse, Inc.

Fox Parry, Consultant, Electric Research and Management Corporation

Moris L. Shore, Federal Drug Administration

PANEL MEMBERS (continued)

Brendan Ware, American Electric Power Service

David White, Massachusetts Institute of Technology

John Zaborszky, Washington University

PANEL AGENDA

EACH PANEL WILL COVER THE FOLLOWING:

1. Research Issues
   A. Technical (unconventional technologies, breakthroughs, etc.)
   B. Policy (national security, technology transfer, etc.)

2. Beneficiaries

3. National Perspectives

4. Government Role

5. DOE Role

NOTE: Each panel will be chaired by a member of the respective subcommittee.

APPENDIX B

LIST OF ATTENDEES

WORKSHOP ON ELECTRIC ENERGY SYSTEMS RESEARCH

Committee Members

Andrew F. Corry, Chairman
Retired, Boston Edison

Robert A. Bell
Consolidated Edison

David O. Carpenter
New York State Department of Health

Jose B. Cruz, Jr.
University of Illinois

John J. Dougherty
Electric Power Research Institute

Hans H. Landsberg (Retired)
Resources for the Future, Inc.

David G. Luenberger
Stanford University

Michael T. Marron
University of Wisconsin/Office of Naval Research

Allan G. Pulsipher
TVA

Z. John Stekly
Magnetic Corporation of America

Gregory S. Vassell
American Electric Power Service

Gerald Wilson
Massachusetts Institute of Technology

Presenters

William A. Bonnett for Richard O'Connell
Hawaiian Electric Company

Bronius Cikotas
Defense Nuclear Agency/RAEE

Steinar Dale
Oak Ridge National Laboratory

C. Bruce Damrell
Boston Edison

J.D. Gassert for Samuel C. Thomas
GPU Service Corporation

Abraham Gerber
National Economic Research Association

Fritz Kalhammer
Electric Power Reserch Institute

Daniel Kirshner
Environmental Defense Fund

Willis F. Long
ASEA Power Systems Center

Rene H. Males
Electric Power Research Institute

Martin L. Minthorn, Jr.
U.S. Department of Energy

Richard O. Phillips
Environmental Protection Agency

Robert J. Ringlee
Power Technology Incorporated

Moris L. Shore
Federal Drug Administration

Babu K. Singaraju
Air Force Weapons Laboratory

Joseph L. Smith
Massachusetts Institute of Technology

Panelists

Thomas Dy Liacco
Dy Liacco Corporation

Nicholas Grant
Massachusetts Institute of Technology

Robert Lawrence (Retired)
Westinghouse, Inc.

Francis Fox Parry
Electric Research and Management Corporation

Robert L. Smith for Don R. Justesen
Veterans Administration

Craig Tedmon
General Electric

Thomas S. Tenforde
University of California

Moris L. Shore
Federal Drug Administration

Brendan Ware
American Electric Power Service

David White
Massachusetts Institute of Technology

John Zaborszky
Washington University

Commission on Engineering and Technical Systems

David C. Hazen
Executive Director
Commission on Engineering and Technical Systems
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
(202) 334-2400

Energy Engineering Board

Dennis F. Miller, Executive Director
Frederic March, Study Director
Rosena A. Ricks, Administrative Secretary
Helen D. Johnson, Staff Associate
John Richardson, Principal Staff Officer
Cheryl A. Woodward, Staff Assistant
William Ramsey, Senior Staff Officer
James Zucchetto, Senior Staff Officer