ELECTRIC UTILITIES INDUSTRY RESEARCH AND DEVELOPMENT GOALS THROUGH THE YEAR 2000

Report of the R&D Goals Task Force to the Electric Research Council

JUNE, 1971

"The concern for man and his destiny must always be the chief interest of all technical effort." Albert Einstein

COVER ILLUSTRATION

Artist's Conception of Urban Fusion Power Plant
Courtesy of Oak Ridge National Laboratory Operated by
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COMMENTARY

The Electric Research Council was organized in the spring of 1965 to provide a means by which the various segments of the electric utility industry in the United States could join in cooperatively supporting research of industry-wide importance. The Council consists of twelve industry executives – eight from the investor-owned sector and one each from the United States Department of the Interior, the Tennessee Valley Authority, the American Public Power Association and the National Rural Electric Cooperative Association.

In the fall of 1970, as a major step in charting the industry's future research program, the Council appointed its Research and Development Goals Task Force. The purpose of the Task Force is to establish R&D goals together with priorities, timetables and cost estimates. The Task Force was requested to submit a report to the Council during the summer of 1971.

The present report is the result of the Task Force's work. The Electric Research Council at its meeting on August 4th formally accepted the report and authorized its presentation to Council organizations for their consideration with the inclusion of a Commentary.

The Task Force has made an important contribution to the electric utility industry and the Council accepts the report as a benchmark in the planning of an expanded electric utility industry research and development effort. The Task Force's cost estimates and goals will be useful as the electric utility industry expands its R&D activities. The Council concurs with the sense of urgency expressed in the report concerning the need for a much larger research effort to aid the industry in continuing to provide economic, reliable electric service in future years with minimal environmental effects. It should be recognized that in the near term the Task Force's schedule of expenditures will have to be modified to conform with the availability of funds.

As a step in planning an expanded research program, the Council has named an R&D Finance Task Force to devise an administrative and financial plan for meeting the R&D needs of the industry. As noted in the Task Force's report, the industry will also look to the electrical equipment suppliers and the government for corresponding increased support of electric power research.

At the present time, the utility industry is soliciting funds to assist in building a liquid metal fast breeder reactor demonstration plant. This project, which may cost the industry as much as $300 million, is an R&D effort assigned highest priority by the Task Force. It appears that support of this unprecedented cooperative research undertaking will meet expectations.

Depending upon economic conditions and technical progress resulting from research work, the needs of the industry will on occasion require revision of the priorities and timetables outlined in the Task Force's report. To be responsive to changing circumstances, the Council plans to update this study periodically.

Much of the industry's future R&D effort will be directed toward new forms of power generation, the solution of environmental problems in the power industry and improving the quality of life.

Solving some of our nations most serious environmental problems will require ever-increasing quantities of electricity. The major electric utility industry research objective is to provide this energy in an environmentally acceptable manner.

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August 19, 1971

FOREWORD

This report of the R&D Goals Task Force of the Electric Research Council [ERC] deals with one basic question: what research and development is necessary to enable the electric utility industry to meet ever-growing demands in ways that are not only reliable and economic, but also environmentally acceptable?

The mandate of the R&D Goals Task Force was to review the future needs of the industry and establish R&D goals, together with a timetable, priorities, and cost estimates for reaching these goals. The Task Force was instructed to proceed on the basis of industry needs without regard for the availability of funds. The question of funding is a separate one to be dealt with by a special Finance Task Force of the ERC.

For the purpose of this report, the R&D Goals Task Force has accepted the definition of research and development established by the Federal Power Commission in its Uniform System of Accounts, which is based on Internal Revenue Service Regulations, Section 1.174-2. The pertinent documents are reproduced in Appendix A.

The scope of this report covers both present and potential methods with which to generate, transmit and deliver electric energy. Environmental implications are strong in the chapters on energy conversion and transmission and distribution, but there is a separate chapter devoted exclusively to environmental matters. The report also considers ways for customers to use electricity more efficiently, and new uses for many applications, particularly to improve the environment. It covers system concepts, load growth and load density, existing and potential fuel resources, and energy transport costs. Finally, it covers fundamental research and the administration of the proposed R&D program. In order to keep this report as concise as possible, we have not included the detailed data supporting our recommended program.

In preparing this report, the Task Force consulted with industry technical committees, manufacturers, scientists, consulting engineers, environmentalists, university staffs, Federal Government Agencies, and a great many utility companies. There is included a long list of acknowledgements of those who contributed substantially to the work of the Task Force. The Task Force also studied many reports, treatises, papers, books and other printed material, including foreign publications.

The Task Force approached its assignment knowing that an adequate supply of electric energy is vital to the Nation's strength and progress, improving the health of its commerce and industry and the living standards of its people, and knowing further that for people to use it in the quantities they require it must be produced reliably and economically, and in environmentally acceptable ways. There must be a balance among reliability, economy and the environment that will be in the National interest. If any one of these considerations were to prevail disproportionately over the others we would then fail in our obligations to the public.

The Task Force believes the basic information set forth in this report will enable our industry to carry forward the kind of comprehensive, coordinated R&D effort that will bring important benefits to the environment and to mankind.

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REPORT OF THE R&D GOALS TASK FORCE
TO THE
ELECTRIC RESEARCH COUNCIL

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SUMMARY

INTRODUCTION

The electric utility industry is critically examining its research and development needs. We recognize that research has played an important role in making the electric power system of the United States the most advanced in the world. This system achieves a very high degree of reliability and provides electric energy at a low price to the consumer. Our high standard of living is largely attributable to our high utilization of energy, particularly electricity, to do the work of man. Although our progress in technology is the result of very fine R&D work, we can and must do better.

The electric utility industry has the responsibility to supply electric energy in adequate amounts, reliably, economically, in an environmentally acceptable fashion, and with a due regard for the conservation of our natural resources. To fulfill this obligation will require further improvements and advancements in our overall operations. The rate of progress is largely dependent on a meaningful, well-planned and coordinated research and development program, which must be fully supported by the electric utility industry, the manufacturers of utility equipment, and the government.

At the present stage of technological development, electric operations – all their contributions to man's progress notwithstanding – intrude on the natural environment more than either environmentalists or the industry itself would like. But within our reach is the capability to produce and deliver electricity in ways that will further reduce the environmental consequences and permit man to use electricity increasingly to improve his life.

Ahead are more effective equipment and processes to control stack emissions; breeder reactors that will greatly stretch our supplies of nuclear energy; coal gasification, liquefaction and desulfurization processes that will enable us to use more of this vast energy resource, without present environmental impact; substantially more economical underground transmission of large blocks of power; new concepts to increase power plant efficiency, lessen the waste heat problem, and in some cases to permit distributed generation – many smaller units close to loads, thus reducing transmission requirements. There are even more exciting possibilities. Fusion, for example, if perfected could give us very high efficiency – up to 90 percent – through direct conversion. There is enough deuterium in the oceans to fuel fusion plants for thousands of years.

How far down the road are these new methods and fuels? The answer depends to a large extent on how much money and effort are devoted to their research and development. Many could become commercially available in the next decade or two. But all the money in the world would not give us commercially available fusion next year, or in this decade – possibly not in this century. In fusion and other new technologies there are enormous problems to be overcome step by step in an orderly process. But there are optimum levels of financing. At what the Task Force considers optimum financing, scientific feasibility of fusion could be established in 5 to 8 years and fusion could become commercially available before the year 2000. To cite another example, the breeder reactor could become commercially available sometime during the early to mid 1980s.

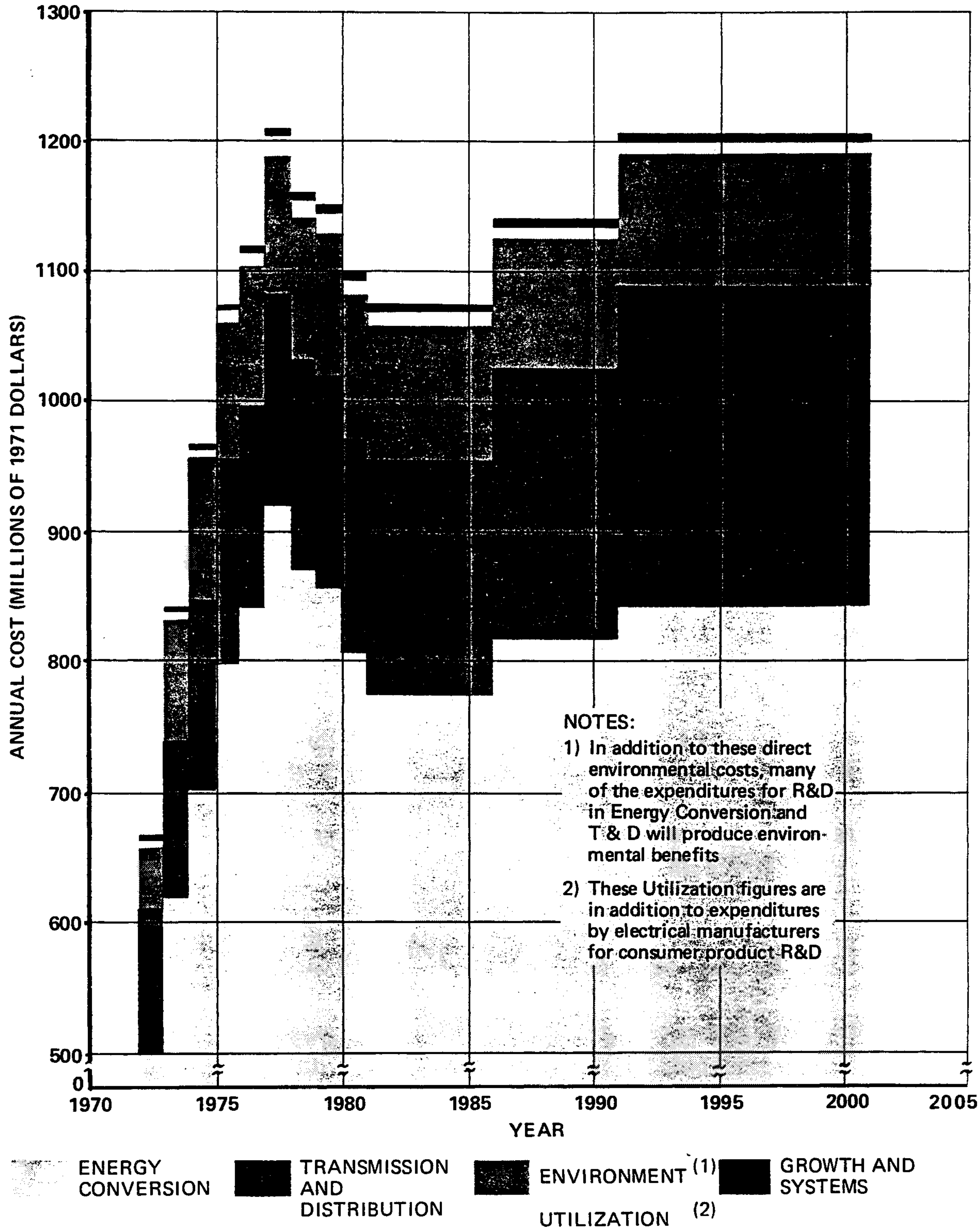
COSTS

The R&D Goals Task Force believes that the goals and funding set forth in this report are necessary, reasonable and attainable – necessary because our industry cannot meet its obligations to customers and society without them, reasonable because they are attainable at a cost representing only a fraction of our industry's capital requirements in the next 30 years, which may approach one trillion dollars, and attainable because they were chosen on the basis of tangible evidence of probability of success. Some will say we have set our sights too low, others too high. Be that as it may, to achieve these goals will require R&D expenditures averaging, over the next 29 years, approximately double the current level of combined expenditures of government, manufacturers and utilities. We estimate these combined expenditures to be approximately $600 million, about half of which is government activity in nuclear research. In terms of 1971 dollars, the program we have set forth will cost an average of $1120 million for each of the next 29 years starting with $667 million in 1972 and peaking at about $1.2 billion in 1977. This leaves a shortfall of some $520 million per year between present levels of R&D expenditures and the average required for the program we recommend. How these additional sums are to be raised is the subject of a separate study by a special R&D Finance Task Force of the Electric Research Council.

Figure 1 and Table I show the total estimated annual R&D costs to be financed by government, industry, utilities and possibly others annually through the year 2000, broken down into the principal areas of R&D – energy conversion, transmission and distribution, environment, utilization and systems. A separate chapter of this report is devoted to each of these areas. These estimates include costs properly chargeable to R&D under the FPC Uniform System of Accounts. Further, because we are unable to foresee many specific projects, we have included "unassigned" costs that reflect our best judgment at this time as to what may be required in these areas in the later years. Updating and revising this report would provide current information about specific projects and a basis for allocating the unassigned amounts.

Present levels of R&D simply will not enable our industry to do what it must do to meet growing demands for electrical energy in ways environmentally acceptable. There are thoughtful and sincere critics today who believe we cannot ever deliver on our promise to supply electricity in the quantities people require without unacceptable environmental consequences. Despite acknowledging that our civilization is founded on high energy use, some express willingness to curtail power use which would slow or even halt economic growth and result in a lower standard of living. But the majority of people, we believe, are willing to give our industry a reasonable time and the financial means to fulfill our promise. We must show steady progress and tangible results to continue to merit their faith and patience.

R & D
Distribution of Total Estimated Annual Cost
to Utilities, Manufacturers, and Government



R & D Goals Task Force Report
to the Electric Research Council,
June, 1971

FIGURE 1

TABLE I

SUMMARY OF TOTAL R&D COSTS TO UTILITIES, MANUFACTURERS, AND GOVERNMENT

(Millions of 1971 Dollars)

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
Energy Conversion	500	619	701	799	841	922	873	857	806	3,875	4,098	8,430	23,319
Transmission and Distribution	110	123	147	157	156	160	160	167	168	913	1,036	2,474	5,772
Environment	47	91	108	103	104	107	109	107	105	503	503	1,006	2,893
Utilization	8	8	8	8	15	15	15	15	15	67	64	128	369
Growth and Systems	2	3	4	5	5	5	5	5	5	22	21	51	133
TOTALS	667	844	968	1,072	1,121	1,209	1,162	1,151	1,099	5,380	5,722	12,089	32,486

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE 1971

But we must not raise false hopes which would jeopardize our ability to meet customer requirements today with what is available today. If people were falsely led to believe that breeder reactors or fusion, for example, are "just around the corner," that argument would be used to oppose facilities we must build now with the technology available now.

BALANCED R&D PROGRAM

There are no one or two magical projects or crash programs that will solve our industry's problems, although clearly the fast breeder, fusion and superconductive transmission, together, could go a long way in that direction. What we need is a balanced R&D program. As we work on long-range goals, we must strive to improve the systems and the fuels with which we are forced to operate today. Conversely, while we seek quick results, we must spend large sums today on projects that may not produce results for many years. Because some seemingly promising areas of R&D inevitably will fail to produce commercially useful end products, we must pursue alternative projects. And we must be willing to suffer failure occasionally when the rewards of success justify the risk. A balanced program is also necessary to assure competitive systems – to provide choices to fit differing requirements, to stimulate innovation by manufacturers, and to avoid undue reliance on a single method or fuel. Finally a balanced R&D program is required to assure complementary systems – to make certain, for example, that we have the new transmission to match the new generation.

R&D BUDGETING

One reason not enough money is being spent on R&D today is that it is particularly vulnerable to budget trimming in both the government sector and the utility sector. R&D expenditures must be made here and now but the payoff may be many years away. R&D is always deferrable without serious short-run consequences. So in the government sector it suffers under the pressure of funds for immediate social and economic and national security benefits. In the utility sector it suffers under the pressure of earnings requirements compounded by inflation and regulatory lag in rate adjustments. We ask that the R&D program set forth in this report be accorded a substantially higher priority in the roster of expenditures than it now receives.

RELIANCE ON MANUFACTURERS

Historically, our industry has relied heavily on manufacturers to do R&D and pass along the costs in the price of the ultimate product. While this has led to many important advances, it is not an altogether satisfactory arrangement. For example, it does not provide for comprehensive system oriented R&D. Manufacturers generally do not invest tremendous sums of money in projects that will not produce a marketable product and return of their R&D investment for many years. They try to remain competitive price-wise not only against other domestic manufacturers, but foreign manufacturers as well. Much important R&D does not necessarily provide opportunity for mass production and profit. Thus the major efforts of manufacturers tend toward short-term R&D that will produce salable products and a profit within a relatively short time span – typically improvements in present technology. Long-range work on new methods does not get the attention from manufacturers that it needs. Some R&D projects are simply beyond the capability of a single manufacturer. Further, reliance on manufacturers does not give our industry the control over its own future that it needs to discharge its responsibilities to society. While we will continue to expect much from manufacturers, we cannot merely take what is given us to work with. We have an obligation to take the future more into our own hands.

PRINCIPAL FINDINGS

Following are our principal findings:

1. As man's use of energy has increased, the quality of his life has improved. As for electrical energy, today's complex civilization could not exist without it.
2. All forms of energy used today affect the natural environment to some degree. Electricity is no exception – there is no available means today to produce or deliver electricity without some impact on the environment.
3. Nevertheless, man will not turn back in his quest for an improved life. Despite the environmental problems, man's use of energy will continue to increase and the portion of energy converted to electricity will increase even faster. Electric demand will multiply six to eight times by the year 2000 as man turns increasingly to electricity as the most efficient and clean form in which to use energy.
4. Wise use and conservation of energy are in the national interest. Presently usable energy resources are finite. Our nation presently imports about 22 per cent of its petroleum supply and 12 per cent of its total energy needs.
5. Consistent with wise use and conservation, there are many new uses of electricity which should and can be developed to improve man's life, especially to help him solve environmental problems such as waste disposal, water treatment and pollution-free mass transportation.
6. It is the responsibility of the electric utility industry to assume leadership in solving the environmental and other problems associated with production, transmission and distribution of electricity.
7. Required in the near term are improvements in present technology, including better utilization of presently usable fuels, and in the long-term new fuels and new methods of production and delivery – in short, a strong research and development effort with balance and clear priorities.
8. Certain fundamental research must also be pursued in such common areas as materials, biology, mathematics and plasma physics which cut across all specific areas of R&D concern.
9. Manpower availability for the total R&D program we recommend must be assessed and steps taken to overcome any shortages. Almost every branch of science and engineering is represented in this program. If our R&D program is assumed to be 50 percent equipment costs and 50 percent manpower costs, then at an estimated cost of $50,000 per scientist/engineer man-year (including administrative and technical support), some 11,000 man-years on average will be required for each of the next 29 years.
10. Comprehensive system concept studies are required to anticipate the general character of power systems 10, 20 and 30 years hence. For example, should we anticipate remote, large capacity "generation parks" with their own fuel processing and waste disposal systems, or should local conversion systems be distributed throughout a power system? Can we combine the conversion of fuels to electric energy with other processes to produce closed cycles, such as incineration of garbage or using waste heat for desalting, space heating and agri-

culture? Alternatives such as these must be studied for their relative social advantages as well as their technical advantages, taking into account local conditions in different parts of the nation.

11. Much valuable research on future power systems has been done. We have the foundation on which to expand a comprehensive and unified program for R&D.

12. There is serious need for a coordinated R&D program for those aspects of the electric power industry which affect the industry as a whole. R&D heretofore has been planned and carried out largely by individual entities – government agencies, manufacturers, universities, the EEI and utility companies – without the degree of coordination required for an optimum program. Establishment of the Electric Research Council was an important step toward coordination of effort.

13. As a result of our investigations, we are persuaded that the manufacturers, government agencies, universities, utilities and others are eager to cooperate in a unified approach to solving the R&D problems of our industry.

14. There is need for administrative machinery to coordinate and implement the comprehensive R&D program we recommend.

15. Present levels of R&D funding are inadequate; financing the level of R&D recommended in Table I should have high priority within the electric utility industry, by suppliers of utility equipment, and by government.

16. The work of this Task Force needs to be updated periodically, preferrably every 2 to 4 years, with goals and priorities modified if necessary in the light of conditions at review dates.

GOALS

The goals of research and development may be stated in specific or broad terms. In specific terms, the goals of this report and the dates by which we think they can be achieved, together with the necessary level of funding, are contained in the subsequent chapters of this report. In the broadest sense the goals of R&D in this industry are the large goals of the industry, itself. There are seven such broad goals, as follows:

1. *To produce, transmit and distribute electric energy in ways that are compatible with a healthy and pleasant environment.* Thus in the following chapters we focus R&D attention on projects to control power plant emissions, minimize the waste heat problem, develop more economic underground transmission, minimize transmission distance and maximize utilization of sites.

2. *To satisfy the increasing demands being put on our systems.* By charter, utilities are obligated to provide safe, adequate and proper service to their customers. It remains our responsibility to provide the amounts of electric energy people require to improve the quality of life, to promote better health, to raise the standard of living, to solve environmental problems such as water treatment and waste disposal, and to produce the goods and services which are the lifeblood of our society. To the extent R&D efforts overcome environmental problems, they will help utilities get necessary facilities built in time to meet growing demand. R&D also can help meet load growth by developing new energy sources and delivery systems.

3. *To serve customers reliably.* Much of the R&D outlined in this report is designed to further improve reliability.

4. *To keep the price of electricity as low as the costs of doing business, including costs of R&D, environmental protection and reliability, will permit.* To this end we have proposed R&D to achieve more efficient systems, give us options and provide competition among systems and manufacturers, improve utilization of present fuels and develop new fuels, and discover ways to improve load factor and utilization of facilities.

5. *To minimize the drain on natural resources.* Thus the breeder reactor, which will stretch our nuclear fuel supply greatly, and new fuels and ways to use them, rank high in our recommended R&D program. This would assure adequate fuel supplies and reduce our dependence on foreign sources. Likewise, ranking high is better utilization of present fuels, such as coal gasification to convert a lower grade of fuel to more usable form; this would reduce excessive demand on high grade fossil fuel resources which have value for uses other than fuel.

6. *To increase the efficiency of consumer use of electric energy.* We propose R&D to find ways to make a kilowatthour do more useful work, to give the customer more for his kWh. This includes research into new thermal insulating materials and more efficient energy utilization devices, particularly lighting, heating and air conditioning.

7. *By doing all of the above, to enable people to use increasing amounts of electricity to solve other environmental problems, in short to make a positive contribution to improving the environment.* Electrically-powered transportation, waste disposal, recycling, sewage and water treatment, agricultural uses to make man less dependent on nature and improve his diet, and many other environmental uses of electricity add up to a number of specific R&D goals in the chapter on Utilization.

PRIORITIES

Priorities must be established, and we recognize that this is a judgment matter. This report establishes four categories of priority, as follows:

Priority 1 – Critically Important: projects having an indispensable effect on all of our goals, which by their nature must receive first attention.

Priority 2 – Very Important: projects having a somewhat less intense impact, but which nevertheless must be included in any meaningful R&D program.

Priority 3 – Important: projects of significance to future planning and continuing operations.

Priority 4 – Desirable: other projects which are useful to accomplish stated goals.

A ranking less than Priority 1 does not mean the project is expendable. Indeed, lack of support for lower priority items would not be consistent with our need for a balanced research and development program.

From the many Priority 1 items in the several chapters, the Task Force has agreed that 11 areas of R&D are most critical and must go forward immediately and concurrently with adequate funding. By highlighting these 11 critical areas of R&D we do not wish to detract from the need for R&D in other parts of the total program contained in this report. But these 11 require special emphasis. By chapter heading, they are:

ENERGY CONVERSION

– Bring the fast breeder reactor to commercial availability by the mid-1980's.

– Steadily improve conventional systems, including fuel processing, especially coal gasification.

– Establish scientific feasibility of fusion within 5 to 8 years and make fusion commercially available by the end of the century.

TRANSMISSION & DISTRIBUTION

– Develop 4 to 10 times higher capacity bulk power transmission, overhead and underground, ac and dc, and narrow the cost differential between overhead and underground transmission.

– Start now to build adequate test facilities to help carry on the transmission and distribution R&D program.

ENVIRONMENT

– Rapidly improve the technology and equipment for the control of oxides of sulfur and nitrogen, and particulates resulting from the combustion of fossil fuels.

– Develop methods of further reducing radiation release associated with the overall nuclear cycle.

– Develop better methods to utilize and/or dissipate waste heat.

UTILIZATION

– Develop user equipment to improve the environment, including electrochemical batteries and other components for electric transportation.

– Explore ways for the user to more efficiently utilize electric energy.

SYSTEMS

– Develop a National Fuels Model as a means to update continually the physical and economic availability for the next 30 years of the energy sources which may be used in the United States for conversion into salable electric power. It would cover usage, discovery, the costs of raw material recovery, refining, transportation and conversion.

RECOMMENDATIONS

The Task Force recommends as follows:

1. That the R&D program set forth in subsequent chapters, including the time tables and level of financing, be adopted by the Electric Research Council as a necessary and attainable set of R&D goals for the industry.
2. That the Electric Research Council take such steps as within its power to assure that the necessary financing is made available from utility, manufacturer, government and other sources.
3. That the Electric Research Council assume leadership in establishing the necessary administrative machinery to coordinate and carry out this program as set forth in Chapter 8.
4. That the work of this Task Force be reviewed and updated periodically, preferrably every 2 to 4 years.
5. That widespread publicity be given to this report and to the determination of the industry to pursue vigorously the necessary level of R&D, and thus to gain public support for the additional revenues a program of this magnitude will require.

CHAPTER 2

ENERGY CONVERSION

The largest portion of the customer's bill reflects costs of power production, that is, energy conversion, and that is where the bulk of our industry's R&D dollars must go. There are strong environmental benefits implicit in all R&D for energy conversion. Following is our recommended program in this vital area:

SPECIFIC GOALS

1. Establish Nuclear Breeder Reactors as being commercially available for purchase by the mid 1980's for central station baseload applications.
2. Improve present methods of generation in efficiency, reliability, and environmental impact. Continue development of gas turbine-steam combined cycle.
3. Establish scientific feasibility of Nuclear Fusion within 5 to 8 years and make it commercially available for purchase by the mid 1990's for central station base-load applications.
4. Establish gasified coal fuel as economically available for gas turbines, MHD and conventional boilers by 1975. Continue research on other methods of fuel preparation such as hydrogen production and solvent processing.
5. Establish open cycle MHD as being commercially available for purchase by the mid 1980's, using gas, oil, coal, or coal derived fuel, for central station base-load applications topping either steam or gas turbines. Establish the MHD portion of these combined cycle plants for peaking and emergency power requirements.
6. Establish Fuel Cells in the 10-20 MW size range as being commercially available for purchase by the late 1970's for substation application, fueled by natural gas, hydrogen, or fuels derived from coal or oil.
7. Continue research on high energy bulk storage batteries for peaking purposes.

8. Continue R&D for unconventional cycles such as potassium-steam binary cycle and Feher CO_2 cycle. Continue research on thermionics for topping nuclear and fossil generating plants.
9. Proceed with additional research on solar energy at a moderate funding level.
10. Continue basic research for new methods of energy conversion.

PRIORITIES AND COSTS

Figure 2 shows the estimated annual cost in the area of energy conversion R&D. Table II shows the priorities and cost by years for each of the recommended programs.

PROJECTS FOR FUTURE CONSIDERATION

Other methods of energy conversion were investigated during the preparation of this report, but not included on the present "recommended" list for various reasons.

Some methods, such as Geothermal, Air Storage Peaking and the liquid hydrogen-fueled rocket type engine, did not seem to hold sufficient promise for all sectors of the industry, but rather for specific, ideally located segments. We would hope these methods would be supported by manufacturers and local groups of utilities as warranted. Breakthroughs in any of these areas might make these methods more attractive to the industry at large.

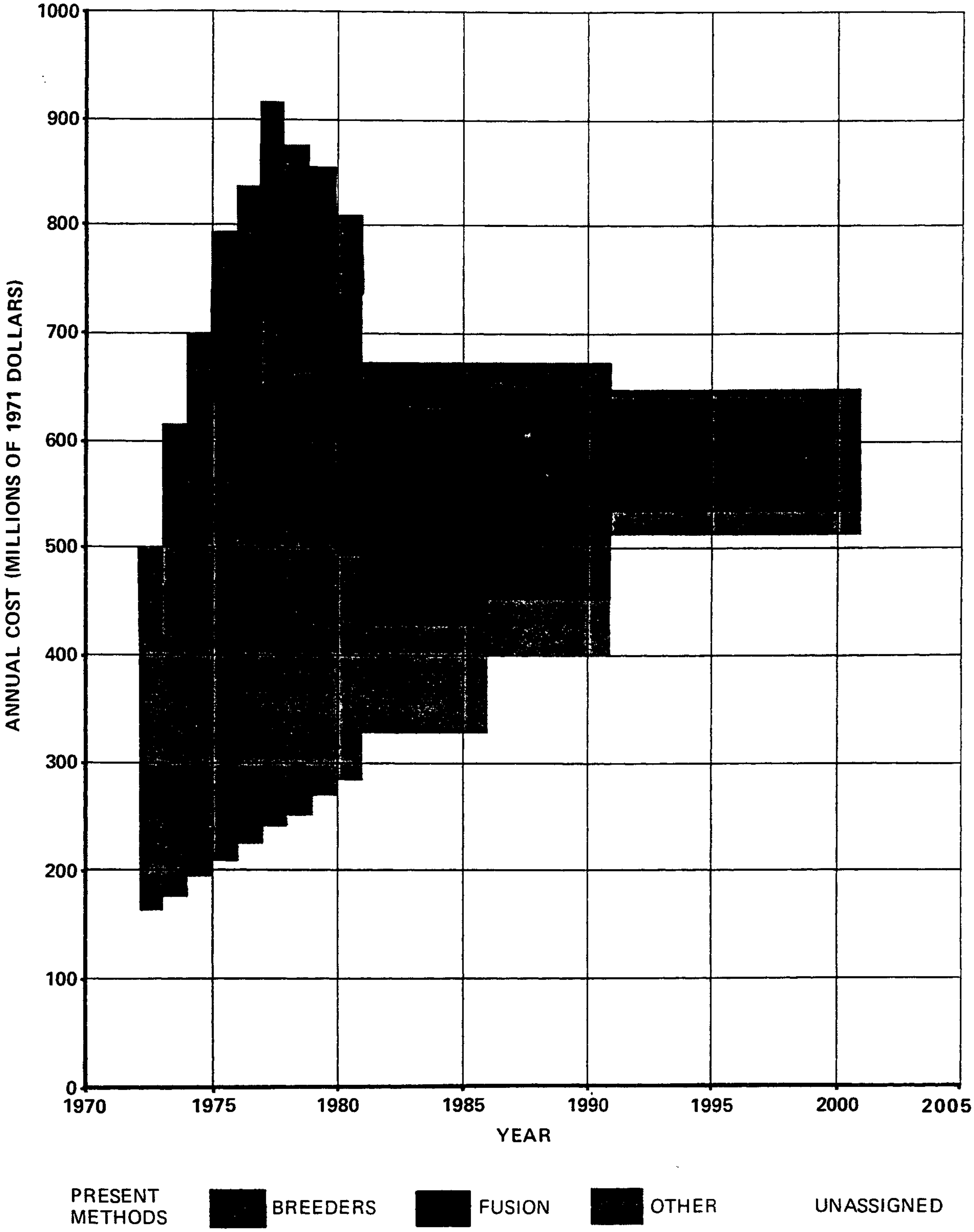
Other methods such as Tidal Power or Thermoelectric Converters did not offer sufficient promise for success at the present stage of development or rewards that would justify the necessary R&D investment. Again, this is not to say that manufacturers or local interest groups should be discouraged from efforts either underway or proposed to develop these methods of generation. Breakthroughs could encourage us to take a second look. Also, changing technological, sociological or economic conditions could lead us to a reevaluation of these methods.

GUIDING PRINCIPLES

In deciding on specific goals for R&D in energy conversion, we were guided by 10 principles, each related to one or more of the seven general goals set forth in the Summary Chapter. These principles are:

1. Aggressively pursue a balanced R&D program that will keep energy conversion options open. Opportunities for short term benefits to the industry and the public cannot be passed by in anticipation of larger benefits in the longer run, no matter how much greater the potential long-run benefits; nor can long term R&D be sacrificed for short term gains. And in both the short and long term there is need for alternatives. In neither the short term nor the long term do we know of any single concept so promising in every area of importance to the industry and the public that it would justify scaling down alternative efforts.
2. Assure that there will be several competitive means of generating electricity to provide choices to fit differing requirements, to stimulate innovations by manufacturers, and to avoid excessive dependence on one or two systems, or on designs which have limited opportunity for substantial further improvement.
3. Direct research toward methods which do not place excessive demand on our precious high grade natural fuel resources. Such demand would cause not only instability of price and insecurity of supply, but could also waste irreplaceable commodities having great value for uses other than fuel.

ENERGY CONVERSION R & D
Distribution of Total Estimated Annual Cost
to Utilities, Manufacturers, and Government



R & D Goals Task Force Report
to the Electric Research Council,
June, 1971

FIGURE 2

TABLE II

ENERGY CONVERSION R&D
SUMMARY OF COSTS TO UTILITIES, MANUFACTURERS AND GOVERNMENT

(Millions of 1971 Dollars)

Priority	Project	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTALS
1	Breeders	250	340	369	427	432	476	415	331	208	500	250	200	4,198
	Fusion	50	60	95	110	135	160	170	215	245	1,000	1,000	1,000	4,240
	Present Methods	165	180	195	210	225	240	255	270	285	1,650	2,025	5,175	10,875
	Fuel Processing	8	10	10	15	10	6	2	2	2	5	5		75
	Subtotal	**473**	**590**	**669**	**762**	**802**	**882**	**842**	**818**	**740**	**3,155**	**3,280**	**6,375**	**19,388**
2	MHD – Open Cycle	4.2	4.4	4.7	9.5	16.2	14.4	5.0	4.5	30.0	120.0	25.0	–	237.9
	Fuel Cells	6.5	8.0	4.0	4.0	3.0	2.0	2.0	2.0	2.0	5.0	–	–	38.5
	Bulk Energy Storage	5.0	5.0	6.0	6.0	4.0	4.0	5.0	5.0	5.0	5.0	10.0	–	60.0
	Subtotal	**15.7**	**17.4**	**14.7**	**19.5**	**23.2**	**20.4**	**12.0**	**11.5**	**37.0**	**130.0**	**35.0**	**–**	**336.4**
3	Unconventional Cycles	6.0	6.0	9.0	9.0	6.0	4.5	3.0	3.0	3.0	7.5	–	–	57.0
4	Solar Energy Conversion	3.0	3.0	4.0	4.0	4.0	8.0	10.0	15.0	17.0	45.0	30.0	25.0	168.0
	MHD-Liquid Metal	0.3	0.8	0.8	1.0	1.0	2.0	2.0	5.0	5.0	10.0	5.0	–	32.9
	MHD-Closed Cycle	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5	25.0	45.0	30.0	115.0
	Thermionics	1.0	1.0	2.0	2.0	3.0	3.0	2.0	2.0	1.0	2.5	2.5	–	22.0
	Subtotal	**5.3**	**5.8**	**7.8**	**8.5**	**9.5**	**15.0**	**16.0**	**24.5**	**25.5**	**82.5**	**82.5**	**55.0**	**337.9**
	TOTALS	**500**	**619**	**701**	**799**	**841**	**922**	**873**	**857**	**806**	**3,375**	**3,398**	**6,430**	**20,119**
	Unassigned	—	—	—	—	—	—	—	—	—	500	700	2,000	3,200
	Totals Including Unassigned	**500**	**619**	**701**	**799**	**841**	**922**	**873**	**857**	**806**	**3,875**	**4,098**	**8,430**	**23,319**

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE 1971

4. Make fossil fuels adaptable to more exotic power generation devices.
5. Improve power plant efficiency to conserve fuel, minimize waste heat and keep power costs reasonable.
6. Improve reliability to minimize requirements for backup capacity and to assure continuity of service.
7. Provide for the most economical mix of power generation methods, with consideration for peaking, intermediate and base load operations, decentralized small generation and energy storage facilities.
8. Design future energy conversion systems with the aim of minimizing transmission requirements to the extent possible.
9. Make most efficient use of plant sites by planning to install maximum feasible capacity on each site.
10. Maintain flexibility to adjust priorities to fit changing conditions and take advantage of emerging commercial technologies.

PRESENT METHODS

Apart from the SO_X, NO_X, particulate matter and other environmental matters covered in the chapter on Environment, there is considerable room for improvement in present energy conversion methods. While the chief efforts of the Task Force have been to concentrate on new means of power production because it requires more planning and evaluation than does R&D on present methods, our most important short-range goal is to make present means of generation more reliable, more efficient and less objectionable from an environmental point of view. Much of the needed R&D in "Present Methods" falls into the category of product improvement, the cost of which is expected to be borne largely by the manufacturers and passed on to utilities in the prices they pay for equipment. Further, in our cost estimates for "Present Methods" in future years, many currently new concepts will have become "Present Methods." For example, most of the breeder research money in the 1990's is included under "Present Methods" in these years.

The estimated present annual cost of R&D in "Present Methods" is on the order of $150 million. For future years we have projected the cost of R&D on present methods in proportion to estimated total MW in service at that time.

FOSSIL-FIRED

In the case of fossil-fired units, problems of decreasing availabilities, increasing forced outages and increasing outage duration must be overcome. While much R&D is in progress by manufacturers in cooperation with utilities, such R&D must continue and indeed be expanded to improve reliability and efficiency.

Specifically, in the area of combustion turbine generators, we must seek to (1) increase MW output per unit, to perhaps as high as 250 MW; (2) improve metallurgy for higher temperature operation and improved efficiency; (3) make units adaptable to fuels such as residual oil, heavy distillate oil, crude oil and gasified coal; (4) improve peripheral hardware for improved reliability; (5) increase time between required overhauls, and (6) reduce noise, exhaust plume and odor.

In steam generators, we must (1) improve reliability, particularly tubing; (2) reduce startup time; (3) improve reliability of controls; (4) increase MW rating, (5) improve combustion efficiency, and (6) reduce noxious effluents.

As for steam turbine generators, we must (1) improve turbine blade design for higher reliability; (2) develop higher rated units, perhaps on the order of 2500 MW by the mid 1980's; (3) improve reliability of bearings, controls and peripheral equipment; (4) investigate further superconducting generator fields for improved efficiency and reduced size; (5) improve generator winding availability by improved insulation and winding support methods, and (6) investigate a bottoming cycle to replace large, expensive low pressure turbines; that is, find a way to discharge I.P. turbine exhaust to a heat exchanger with a different heat transfer medium, liquid or gaseous, that will extract energy from steam and generate power with smaller equipment than low pressure turbines.

In the area of auxiliary plant equipment, we must (1) improve reliability and efficiency of electric motors, fans, pumps, controls and other equipment; (2) increase ratings of auxiliary equipment for larger size units, and (3) reduce noise.

There is high promise in the combined cycle, and we must continue development of the gas turbine-steam combined cycle.

FUEL PROCESSING

Gasification and solvent processing of coal, and hydrogen production (to be used as fuel) are proposed to provide high quality clean fuels for generating plants. The refined coal products are projected to be economically attractive in the fuel market. Transmission of hydrogen by pipeline to the point of use could be an attractive prospect in the future as natural gas fuels dwindle.

The main purpose of improved fuel processing, of course, is to reduce pollutants from the combustion of fuels. Improved heat rate and ease of transportation of the fuel to the point of use are additional benefits which add economic attractiveness to these processes.

Considerable work on fuel processing is in progress under auspices of the Federal Government, with mid-1970 target dates for commercial availability. Gasification and solvent processing techniques are being perfected, areas of limited understanding have been identified and work in these areas is underway.

We project costs on the order of $75 million over the next 20 years for fuel processing R&D, the bulk of it between now and 1977.

HYDRO INCLUDING PUMPED STORAGE

The state of the art for conventionally designed hydropower installations, including both natural flow storage and pumped storage, has developed to the point where further refinements of present methods will yield only minor benefits.

An increase in hydropower, as a "peaking partner" for large base load fossil fuel and nuclear powerplants, is now desirable. The need for hydro peaking capacity will become more attractive with the ever increasing size of steam powerplants. Also, the fast response and great flexibility offered by hydropower are essentials in meeting demands and providing system stability in large interconnected power systems. The hydropower potential in the United States is many times greater than that presently developed. However, many of the more desirable sites have already been developed. Now we must look to the second, third, and fourth best sites if development is to continue. To make these sites economically attractive, departures must be made from the conventionally designed hydropower installations. Changes must occur in both civil works and powerplant equipment. Also, a new look must be taken at the present methods, procedures, and values for assigning hydropower benefits.

Hydro pumped storage can effectively increase the capacity factor of high capital, low operating cost energy sources such as nuclear units.

Areas in which research and development are needed include: (1) Reservoir sealing – Particularly needed for high reservoirs for pumped storage which often are located considerably above the natural water table in soil that is difficult to seal. (2) Large high efficiency solid-state frequency converters – This equipment is needed in sizes through 600 MW. This would permit turbines or pump-turbines to run at best efficiency for head and load conditions. In addition, for pumped storage the starting motor could be eliminated and the generator-motor size could be limited to that required for power generation. (3)

Quick-erect dams – Such as inflatable rubber or other improved types and methods to be used for low head power installations or for surcharging existing installations. (4) Peaking potential survey – This would cover present potential and how much increase can be obtained by improving present installations by modifying present units, installing additional units at existing sites, increasing power head, installing afterbay dams, etc. (5) Powerplant packaging – Unitized turbine, generator, transformer, governor, controls, etc. [No powerhouse structure and minimum concrete foundation.] Standard arrangement and a family of sizes could approach "off-the-shelf" design and equipment supply. (6) Hydro-thermal optimization – Programs and guides need to be developed to permit the industry to make the most economical use of the various power resources in a large complex system. Both monetary and ecological benefits need better value assignments and clearer definitions. This should include the effects on the power system and the society which it serves for both existing power sources and the development of new sources. (7) General – Research and development needs to be continued in such areas as reducing costs of large pressure conduits, eliminating draft tube surging, evaporation reduction, tunneling, etc. It is also expected that new ideas for potential industry-wide benefits will arise which will warrant being developed.

It is estimated that R&D expenditures should be on the order of $1 million per year for hydro and pumped storage energy conversion from now through the year 2000.

NUCLEAR FUELS

There is also continuing need for R&D on nuclear fuels. Numerous contributors have suggested a high priority be given to plutonium recycle, which although now being offered commercially requires further improvement. Other areas requiring further improvement are fuel quality and performance, fuel failure mechanisms, core analysis computer methods and fuel utilization. R&D is required also on recycled fuel for advanced reactors such as the High Temperature Gas Reactor (HTGR), handling and shipment of spent fuel and by-product plutonium, and improved methods of handling reprocessing wastes. The possibility of beneficial uses for fission products needs continuing study.

Much of this necessary work can be expected to be done by manufacturers as they seek to improve their product. In the case of fuel development for new advanced reactors such as breeders, we have treated the fuel problem as part of the overall development of such reactors and there does not appear to be a need at this time for the utility industry to become directly involved in enrichment R&D. Specific needs will dictate what portion of nuclear fuels research requires substantial industry-wide support.

NUCLEAR SAFETY R&D

Our industry has met and will continue to meet all nuclear safety and licensing requirements established by the responsible agencies of government.

However, safety and licensing requirements are constantly subject to change. Licensing agencies continue to raise questions and require large margins of conservatism in the design of present light water reactors. Further research is needed to more fully answer the questions and help determine the proper margins and allowances.

A large amount of R&D on nuclear safety is being done by the AEC, manufacturers and individual power company applicants. In our effort to be responsive and responsible, additional industry input would be useful. This would increase the body of knowledge concerning nuclear safety and contribute to greater public confidence. In some cases, it could lead to less redundancy. While we must be prepared to do all that is realistically necessary, we should not be required to design and build in safety margins that in no way add to safety.

The broad areas in which our industry could be expected to contribute include accident analysis. Data on probabilities, timing and reasonable upper limits on events following postulated accidents are needed, such as fission release and transport, hydrogen production, cleanup, cooling and other post accident phenomena.

More research is needed on long-term radiation and thermal cycling effects. Methods need to be developed for better in-service inspection of critical reactor system components.

Analytical methods and data relative to reliability need to be perfected and applied to better determine whether present redundancy is either inadequate or excessive. Seismic design and testing standards also need to be developed further. More needs to be done on radioactive waste handling, shipping and disposal. Ultimate disposal of fuel processing wastes at reprocessing plants should be recognized as being part of the utilities' overall waste disposal problem.

Nuclear safety aspects of new reactor types should be assessed by the utility industry as well as by the government and manufacturers. The question of licensability of fast reactors requires utility industry input. Safety aspects of other advanced reactors also must be assessed.

The AEC and manufacturers are presently spending about $40 million per year on these matters. Some additional nuclear safety R&D is related to specific plant applications and these costs have been borne largely by applicants and allocated to plant cost. Additional funding requirements for industry-wide nuclear safety R&D are difficult to predict because they will depend on what projects become most urgent and are chosen for broad support, the level of effort required for each, and which are to be borne by applicants and included in cost of plants.

BREEDER REACTORS

Breeder reactors utilize neutrons produced in fission reactions to bombard blanket materials, thereby creating a new fissionable material. Since more than one neutron is produced per fission, there are sufficient neutrons available to sustain the fission chain reaction and to produce significant amounts of new fissionable material for use in other reactors if neutron losses are kept to a minimum. Heat is extracted from the reactor by coolant.

There are two basic types of breeder reactors – "thermal" and "fast" breeders. Thermal breeders have a moderator material such as water for slowing down neutrons. Fast breeders do not.

"Thermal" breeders cannot breed on plutonium being produced in present light water reactors. It is expected that thermal breeders operating on U-233 fuel will not produce excess fuel for use in starting up other reactors as rapidly as "fast" breeder reactors operating on plutonium fuel. Consequently they cannot provide bred fuels fast enough to keep up with the expected growth rate of the power industry without adding some uranium enriched in U-235.

Various breeder reactors of both basic types have been promoted by industry groups, manufacturers and governments. The Liquid Metal Fast Breeder (LMFBR), described below together with other promising types of breeders, is supported heavily by the AEC – at a level of about $100 million per year – and has had far more support in some sectors of the industry than other reactors still in the developmental stage. It is regarded by the R&D Goals Task Force as number one priority in power generation development in this decade.

ADVANTAGES OF BREEDERS

The main incentives for developing breeder reactors are (1) to conserve and extend fuel resources, and (2) to reduce fuel costs and, hopefully, total power costs.

The light water reactors and to a lesser extent the high temperature gas cooled reactors now commercially available to the U.S. power industry require high usage of our uranium resources. Light water reactors use effectively only about 1% of the contained energy of mined uranium. HTGR's are roughly twice as good and their use may be important in holding down fuel demand and costs until breeders are developed and accepted by the industry and the public.

Breeders virtually eliminate concerns about ore supply and enriching plant capacity and associated costs. Fuel burnup costs are expected to be roughly a tenth of those for light water reactors and, consequently, represent substantial protection against rising fuel costs.

The EEI Reactor Assessment Panel forecast total fuel cost savings for commercial fast breeders compared to light water reactors of about one mill per kilowatthour based on constant uranium and enriching costs. If late in this century uranium and enriching prices were to double, the fuel cost advantage for breeders over light water reactors could increase by as much as 1.5 mills per kilowatthour. This increase represents about $12 million a year for each 1100 megawatt reactor or about $1 billion a year for each 100,000 megawatts of U.S. nuclear capacity. Therefore, even if early breeders barely break even on total power cost, there would be substantial benefit as fuel costs continue to rise.

Breeders also may increase the value of plutonium by as much as 50% compared to its value if recycled in present reactors. A $4 a gram increase over typical recycle value of $8 a gram in light water reactors would result in a saving of about a half million dollars a year for each 1100 megawatt light water reactor, assuming the use of breeders did not materially affect the high capacity factor operation of light water reactors.

BREEDER ALTERNATIVES

Four breeder types are being worked on seriously in this country at the present time. Two are thermal breeders – the light water thermal breeder reactor (LWBR) and the molten salt thermal breeder reactor (MSBR) – and two are fast breeder reactors – the liquid metal fast breeder reactor (LMFBR) and the gas cooled fast breeder reactor (GCFR).

Industry, like the AEC, gives its greatest support to the LMFBR, but there is also industry support for the GCFR, primarily as an alternate or backup fast breeder. The thermal breeders also have some support by industry as a backup for the LMFBR, and some see them as the only acceptable way to get breeders licensed for an urban site in a reasonable number of years.

Following is the status of the two thermal and two fast breeders now being seriously pursued:

(1) *Light Water Thermal Breeder Reactor (LWBR)* – Developmental work, under the AEC's naval reactors program, is presently directed toward demonstrating feasibility. A demonstration LWBR core is planned for operation about 1975 in the Shippingport plant. Cost of this program is likely to total about $150 million by 1976 and there appears to be adequate funding.

When results become available from the Shippingport program the concept can be assessed for commercial use. It might be possible for such a reactor to be commercially available for sale to power companies before 1980 if manufacturers were to adopt it, but possibly not as a breeder.

(2) *Molten Salt Thermal Breeder Reactor* (MSBR) – This reactor concept needs an experiment to prove technical feasibility of the concept as a breeder. If the breeder is not in the picture, the power industry does not have a great incentive for developing molten salt converters. When a large MSBR feasibility experiment of sufficient size demonstrates that the technology required for a commercial breeder is in hand, the power industry would have the evidence it needs to consider going ahead with a demonstration MSBR. If the feasibility experiment were

done by 1980, further development could go forward on a schedule about 10 years later than that now foreseen for the LMFBR. Development costs would be expected to be similar.

Further development work would also depend on where the LMFBR, gas cooled reactors, light water reactor fuel supply and fusion development stand in the late 1970s or early 1980s. There is considerable concern about the ability to perform maintenance on the MSBR once it has been operated. For all of these reasons the MSBR concept is quite far down the priority list at the present time. But its potential advantages are sufficient to justify continued development, even if fast breeders are successful. These advantages include good fuel utilization characteristics which approach those of fast breeders and MSBR's do not have the same problems relating to siting and licensing.

(3) *Liquid Metal Fast Breeder Reactor* (LMFBR) – Among fast breeders, the LMFBR is farther along and appears capable of becoming commercially attractive at the earliest date. If a commitment were made in 1971 and a construction permit obtained in about two years, the first LMFBR demonstration plant could be on the line between 1978 and 1980. On the basis of successful operation of LMFBR demonstration plants combined with good experience with the Fermi plant and overseas breeder plants, and further provided economic factors are well in hand, large scale commitments by utilities for fast breeders, could be expected in the early to mid 1980's.

(4) *Gas Cooled Fast Breeder Reactor* (GCFR) – Development of this fast breeder is not as far along as for the LMFBR, but its development can take advantage of gas cooled reactor component experience with the HTGR and fast fuel development for the LMFBR. A GCFR demonstration plant could be undertaken soon if money were available for it. Such a plant as an alternative to an LMFBR plant might benefit sufficiently from HTGR experience and LMFBR basic technology to require less financing beyond its value for power than the earlier LMFBR demonstration plant or plants. Even if there were no cost savings compared with LMFBR, it might well be justified by the potential benefits which this concept might have over the LMFBR. If its development indeed were largely an adaptation of other technology, and if a demonstration plant were built on the schedule suggested above, the GCFR could become commercially available as soon as or soon after advanced high gain LMFBR's.

FAST BREEDER DEMONSTRATION

Construction of a demonstration power plant is the critical task toward developing an economic fast breeder and one in which the electric industry can play the major role. Total project cost for the first LMFBR demonstration plant now appears to be in the range of $400 to $700 million, or an excess over economic cost on the order of $300 to $500 million.

The purpose of the first demonstration plant would be to check out a completely engineered LMFBR power generation facility of modern design in the commercial arena. Licensability of the basic concept for a utility system application would be proven.

Reliability and capabilities of components would be demonstrated. Design criteria and cost data would be established. The plant would provide focus and a practical business input to the technological development program.

The second demonstration plant will probably be either a second LMFBR or a GCFR depending on (1) alternative LMFBR demonstration requirements determined during the early phases of the first LMFBR demonstration, and (2) the degree of success in operation of the Ft. St. Vrain gas cooled reactor; this is a 300 MW demonstration gas cooled unit in Colorado scheduled for completion in 1972.

The Task Force believes there must be *at least* two breeder demonstration plants planned which overlap in construction time. If we do not so plan and act, failure of the first mechanically or through inability to meet expected operating parameters and efficiency would set back the program many years with the result of higher power costs and more rapid depletion of uranium resources. For cost control there must be competition among manufacturers.

The Task Force believes that in the long run a third breeder demonstration plant will eventually pay dividends to the electric utility industry. The third plant would create still further commercial competition and resultant lower costs. In all probability it would be a second LMFBR concept or a GCFR, depending upon the type selected for the second demonstration plant, and would give the opportunity to evaluate a third concept prior to construction of many fast breeders in the United States.

A recent AEC study shows that there is a cumulative savings in the cost of electric energy of up to $358 billion by the year 2020 based on a 1986 FBR commercialization date. Such potential savings warrant a thorough review of FBR concepts and such a review could be well accomplished with three demonstration plants of different design.

Demonstration plant construction must begin at the earliest possible time. The same AEC study shows that for each year that the introduction of the breeder is delayed, there is an annual loss in terms of dollars present worthed to 1971 of over $1 billion. Even if the savings are only a fraction of those indicated in the AEC study, heavy commitments and accelerated action on the breeder program are justified.

Presently it appears that the excess costs above economic power value of the initial fast breeders would be about as follows:

	Period	Excess Cost (Millions)
Fermi	6 years starting about 1971	$50
First Demo Plant	6 years starting about 1972	$300 to $500
Second Demo Plant	6 years starting no later than 1974	$300 to $500
Third Demo Plant	6 years starting about 1976	$300 to $500

BREEDER DEVELOPMENT COSTS

The estimates for fast breeder development indicated in Table II show AEC estimates for breeder development including costs of advanced converters and low gain breeder reactor concepts which will make major technological contributions to the conservation of fissile materials and contribute to the advancement of breeder reactor technology. The total excess costs (over and above economic costs) of three demonstration plants are included. These costs will be shared by utilities, manufacturers and government.

PROBLEMS OF THE COMMERCIAL FAST BREEDER

The industry can expect a whole new set of conditions and must be prepared to meet them, particularly in licensing, scheduling, costs, technology-cost trade-offs, safety and public concern, shipping spent fuel, and disposal of reprocessing wastes. The potential benefits of breeder reactors to the industry and the public are so great that these problems must be overcome.

NUCLEAR FUSION

Efforts to control thermonuclear (fusion) reactions for the production of usable energy have been underway since the early 1950s. Scientific feasibility is yet to be established. The initial impetus resulted from recognition of the possibility of using an essentially unlimited, low-cost fuel – deuterium – for power production, but the other advantages of fusion, described below, are now being recognized as at least as important. There is no question that the achievement of a practical fusion power reactor would ultimately have a profound impact on almost every aspect of human society.

The basic mechanism for producing fusion power is the combining or "fusing" of heavy isotopes of hydrogen, such as deuterium or tritium, with an accompanying conversion of part of the total mass into energy. In order for fusion reactions to occur, dilute mixtures of the nuclear fuels must be heated to temperatures on the order of 100 million degrees centigrade. To obtain useful power from the fusion reactions, the hot reacting gas (plasma) must be continuously confined free from any contact with material walls or contamination, and means must be found for injecting the nuclear fuels, extracting the energy released during fusion, and removing the fusion products.

There are a number of fusion reactions being investigated. Two of the most prominent are deuterium-tritium (D-T) and deuterium-deuterium (D-D). The D-T is the fusion of a deuterium nucleus and a tritium nucleus to form helium-4, a neutron and energy. There are two D-D reactions of about equal probability where two deuterium nuclei fuse together, in one case forming helium-3, a neutron and energy, and in the other case where tritium forms plus a proton and energy.

ADVANTAGES OF FUSION POWER

The principal potential advantages of fusion are as follows:

The deuterium fuel is abundantly available in sea water, low in cost and easily handled. The deuterium present in one cubic meter of water is equivalent to 1,360 barrels of crude oil. Even in inefficient rankine-cycle plants, deuterium could supply the world's energy needs for many thousands of years.

Fusion power, like fission power, would produce no combustion products.

The only radioactive by-product would be tritium, much of which could be recycled in the reactor as a fusion fuel. The engineering problems associated with handling tritium, while not insignificant, do not appear to be insurmountable.

Fusion power plants promise to be more efficient than today's power plants if the higher temperatures involved could be used with topping cycles. Furthermore, there is a possibility of achieving the direct conversion of fusion energy into electricity. In either case, the production of waste heat per unit of electric energy produced would be reduced.

A fusion reactor would not contain enough fuel to produce a nuclear excursion and the nature of the fusion process itself eliminates any chance of a nuclear incident.

Other potential advantages for fusion reactors include the possibility of using the fusion-produced neutrons in a fission breeder combined cycle, or as catalysts in chemical reactions; a plasma torch to reduce wastes to their constituent atoms or for processing mineral ores; and the possibility of using fusion energy to produce photons (by injecting impurities into the plasma) which could produce hydrogen from water at low cost.

PRESENT STATUS OF FUSION RESEARCH

At the time that fusion research was de-classified in 1958, optimism ruled. It appeared a simple matter to scale up the known interactions between magnetic fields and fusion plasmas to sizes which would confine useful quantities of plasma at ultra-high temperatures. But as the first wave of experiments came on the line, results were disappointing, so disappointing in fact that pessimism pervaded the field for several years. In this interval, however, considerable progress was made in understanding plasma theory and in matching theory to experimental results.

In the past few years progress has been much more rapid than in the past. Confinement of plasmas under conditions of temperature, density and time which approach those necessary to demonstrate the scientific feasibility of fusion power has been achieved in several devices. Both in this country and abroad a number of experiments are now in operation or nearing completion, any one of which could produce the scientific basis for the ultimate experiment which will demonstrate beyond any doubt that control of fusion reactions in man-made devices is in fact achievable. It now appears quite probable that at least one such demonstration will occur by the late 1970's but much depends upon the availability of funds.

Currently the AEC's controlled thermonuclear research program is being funded at a level of just under 30 million dollars, 85% of which is spent at the four major AEC laboratories: Princeton Plasma Physics Laboratory, Oak Ridge National Laboratory, Los Alamos Scientific Laboratory and the Lawrence Radiation Laboratory. Some AEC funds are also allocated to universities.

In 1970 the Edison Electric Institute began the support of fusion research at the University of Texas at a level of $100,000 per year. The Texas Atomic Energy Research Foundation, composed of ten Texas power companies is also financing the University of Texas effort at a rate of about $400,000 a year. Recently, the government laboratory at Princeton has received $200,000 in power company support and Cornell University has received a commitment of $250,000 from power companies. The largest industrial group is at Gulf General Atomic in California where research is funded in part by the AEC and in part by GGA funds.

PROBLEMS TO BE OVERCOME

Having noted the immediate status of laboratory work, it is useful to examine more closely some of the engineering and environmental problems that can be foreseen for the fusion reactor development program once scientific feasibility has been demonstrated.

The core of a steady state D-T fusion reactor would consist of a vacuum wall, heat removal ducts, neutron moderating plus tritium breeding blankets, coil shield, magnet, and mechanical support. In addition, there would be heat exchangers, turbines, etc., necessary to complete the power generation cycle, possibly including an intermediate liquid metal loop for a topping cycle.

The vacuum wall presents difficult design challenges because of the requirements for a low sputtering rate, integrity under continuous radiation from 14 MeV neutrons, resistance to corrosion by the coolant, and adequate strength at high temperatures.

Preliminary designs of neutron blankets using lithium have been proposed. Problems include heat removal and pumping, tritium breeding and recovery, and the chemical and safety aspects associated with handling liquid lithium. In addition, the availability of lithium in the United States is not well defined at present.

Much remains to be done in the design of injection systems to introduce the fuel into the reactor and spent gas removal systems. Engineering designs of the heating systems remain to be developed.

The magnetic field requirements of a steady state fusion reactor are unique: a high magnetic field, a large volume and low power consumption. Recent advances in superconducting technology show great promise for fusion reactors but the very large size and possibly complex geometry of the magnet systems will impose severe design problems.

Overall reactor design must accomplish an accommodation of the principal components – vacuum wall, blanket, shield, insulation, superconducting magnets and biological shield – into a structure capable of supporting the weight of the reactor and of withstanding the forces produced by the magnetic fields while also withstanding the effects of intense radiation and heat.

Safety considerations for fusion reactors relate principally to tritium handling, induced activity of the structure and chemical fires. It is anticipated that processing of tritium fuel can take place entirely within the fusion reactor and that residual leakage from normal operation can be kept well within acceptable limits. The probability of an accidental release of a significant fraction of the tritium inventory in a plant can undoubtedly be made very small and the consequences of such a release do not appear to be serious.

The hazards associated with liquid lithium coolant are similar to those of sodium coolants in fission reactors. Neutron-induced activity in fusion reactor structural materials represents a potential problem. The after-heat associated with decay activity will also be a factor in fusion reactor design. Emergency cooling may be required.

COST ESTIMATES

Approximately $400 million has been spent on controlled thermonuclear research in the United States since the beginning of the program in 1951. Another $600 million has been spent in other countries.

Until recently the level of support for fusion research in the United States has been arbitrarily fixed on the basis of factors other than the demonstrated need for specific manpower or hardware. Rather, fusion budgets tended to be established on the basis of a "level of effort" desired by a particular institution and considered appropriate by those setting the budgets. Now, however, fusion progress is becoming limited by the availability of funds. Both federal and nonfederal funding has remained relatively static while the costs of individual experiments has increased. The cost of each major fusion experiment, now about five million dollars, will soon become 15 to 30 million dollars and the cost of new experiments or prototypes to be begun later in the 1970's will probably be on the order of 50 to 100 million dollars. In addition, as fusion research progresses from basic physical theory to advanced engineering and technology, additional funding will be needed for these purposes.

The following cost estimates are necessarily very rough and are based on a number of assumptions. The basic assumption is that the nation desires an efficient and orderly fusion research program aimed at producing commercial fusion power plant capability in the 1990's.

NUCLEAR FUSION RESEARCH PROGRAM

	Millions of 1971 Dollars
Expended Through FY 1971	400
Proposed Research Program	
Demonstration of Feasibility	450
Physics, Engineering and Materials	2,090
Direct Conversion Prototype	300
Thermal Prototypes [2]	400
Demonstration Plants*	1,000
Total, Future	4,240

*Incremental cost for small plants above equivalent fission capacity in large plants. If very large [2000-5000 MW] demonstration plants are necessary, this figure is too low.

Fusion is still an evolving field and it follows that funding recommendations made today could turn out to be inappropriate in the future. An important factor will be progress in the U.S. breeder program. But assuming the breeder program goes well, when all the potential benefits of fusion are considered, the conclusion is inescapable that fusion power deserves a much greater share of the industry's long-range research dollar.

Utilities should begin to seek industrial partnership in fusion research. One or more manufacturing industries should participate in the development of fusion reactors as a first step towards putting fusion power on a commercial basis. Particular emphasis should be placed on the early accomplishment of a direct conversion process.

TIME SCHEDULE

There is no way of foreseeing the obstacles that may be encountered as fusion research progresses. In the prevailing spirit of optimism due to recent significant advances, it is easy to underestimate the technological problems that will inevitably occur. It is very apparent that the design and material problems associated with large fusion reactors have received only the most preliminary examination and, although technology being developed in the breeder programs will in many cases apply to fusion reactors, it nevertheless seems quite likely that unforeseen and perhaps formidable engineering difficulties may lie ahead.

Assuming an adequate level of funding as outlined above, and assuming further that there will be a steady growth in our universities in the availability of scientific and engineering manpower trained in the necessary fields of theory and technology, the following time schedule seems to be realistic for an orderly and efficient fusion program in the United States:

Demonstration of Scientific Feasibility by 1976 to 1979.

Operation of at least two prototypes by 1980 to 1984.

Operation of at least one demonstration plant by 1990.

Sales of fusion reactors on a commercial basis before the year 2000.

PRIORITY 2 ITEMS

Following is a brief discussion of the Priority 2 items in the area of Energy Conversion. A more detailed discussion of these items will be found in Appendix B.

MAGNETOHYDRODYNAMICS (MHD) OPEN CYCLE

An MHD generator converts the kinetic and thermal energy of a moving plasma directly into electric energy by passing a highly conductive gas through a strong magnetic field. MHD is proposed for fossil fired units topping conventional steam cycles; however, development could lead to additional concepts and usage. The increased cycle efficiencies possible could result in significant decreases in thermal effects and conservation of fossil fuel resources.

Investigation is needed to increase the knowledge on the combustion and gas flow phenomena and the effects of the combustion process on generator performance, maintenance and life. Significant research is also required on preheater technology and stack gas cleaning devices to assure an environmentally acceptable process.

FUEL CELLS

Over the past two decades, efforts have been made to develop the technology of conversion of chemical energy directly to electricity (fuel cells). The space program has produced small, successful, but expensive units. It is becoming increasingly desirable to develop this concept for use at the substation level (10-20 MW) to provide economic generation at dispersed locations. One advantage to this would be a reduction in the need for transmission lines and associated rights of way.

Present concepts involve the conversion of fossil fuel in a reformer to produce hydrogen, and reaction of the hydrogen with oxygen in the cell to produce dc electricity for conversion to ac. There is significant reduction both in release of emissions to the air and need for water.

Continued research is needed on various electrolytes, cell life, adaptation of this concept to present systems, and operational modes (whether base load with continual fuel supply or similar to pumped storage hydro with hydrogen produced from water electrolyzed off-peak by a base load plant).

It is estimated that $39 million and 14 years will be necessary to complete the recommended research program.

BULK ELECTRIC STORAGE BATTERIES

Bulk electric storage batteries envisioned for use in power systems would serve a purpose similar to pumped storage with less overall land requirements and environmental impact. As in the case of some fuel cell applications, low cost "off peak" energy would be utilized to charge the batteries so that they could be discharged during peak periods to meet system conditions.

The development of storage batteries with large power and energy capabilities would allow more efficient utilization of installed generating equipment and would permit dispersed siting in and near load centers. This would also have the potential of reducing transmission line and rights-of-way needs.

Some research has been and continues to be done on single cell experiments and many electrodes and electrolytes are being investigated for improving battery energy storage capabilities, performance and rechargeability.

Significant research needs to be undertaken on battery materials corrosion, incomplete discharge, large voltage drops and lifetime of components.

It is estimated that in the next 19 years the continuation and expansion of research plus several pilot models and a demonstration plant by the early 1980's will cost about $60 million.

PRIORITIES 3 AND 4 ITEMS

There are a number of other energy conversion devices that need basic and continuing research over the next 20 years or so. These include thermionic conversion, solar energy conversion, liquid metal and closed MHD cycle and cycles utilizing fluids other than steam.

The Task Force believes that these concepts have potential for long range development, and have included $395 million in the recommended R&D effort of industry, manufacturers and government over the next 20 years.

Details of these other devices and methods can be found in Appendix B.

CHAPTER 3

TRANSMISSION AND DISTRIBUTION

To deliver six to eight times as much energy to load centers – as we will be called upon to do over the next 30 years – without having to build that many more transmission lines, acquire that much more right-of-way, or install that many more substations – requires an accelerated research and development program in transmission and distribution.

SPECIFIC GOALS

Our specific goals in transmission and distribution fit into five broad classifications, where work must proceed concurrently because they are closely interrelated:

A. *Bulk Power Transmission*

1. Develop new and improve existing *underground transmission* systems.

   a) Bring into commercial use one or more systems with the potential of carrying from four to ten times the load of present-day cables at substantial savings in investment. These are needed to meet future requirements, such as high capacity dc cables and three phase gas insulated cables by the late 1970's, cryogenic cables by the mid 1980's and superconducting cables by the 1990's.

   b) Determine the feasibility of advanced concepts of underground transmission so that the industry may take advantage of any breakthroughs, including a study of the transmission of microwave power.

   c) Extend the voltage range of existing insulation systems.

   d) Improve the power transfer capability of "state-of-the-art" systems by forced cooling.

   e) Develop reliable, high-voltage extruded dielectric cables.

   f) Develop EHV cables with taped synthetic insulation.

2. Increase the capacity of existing and new *overhead transmission* rights-of-way by improving design and equipment, both *ac and dc.*

   a) Develop and improve hardware for use on HV, EHV and

UHV lines with emphasis on bundle conductor hardware and devices.

b) Develop ±600 kV dc by 1973 and extend this into the UHV range by the late 1970's.

(c) Make further insulator contamination studies for ac and dc lines and for substations leading to improved performance and reduced contamination flashover.

d) Make further conductor studies in order to control vibrations, increase current carrying capacity and develop design parameters for multi-conductor bundles.

e) Develop further understanding of grounding parameters and new methods of grounding for areas with high ground resistances and of using overhead ground wires to provide better protection against lightning.

f) Further study and control the effects of electromagnetic and electrostatic induction, corona at EHV and UHV levels including acoustic noise, electrical noise, corrosion, lightning and moisture migration in order to improve system designs.

3. Improve designs and equipment for *substations and dc terminals.*

a) Develop circuit breakers that can handle greater fault duties by interrupting at current zero or by changing the characteristics of the fault current, development of high voltage vacuum breakers and development of a successful dc breaker.

b) Develop miniaturized dc terminals incorporating a converter element with both turn-off/turn-on control characteristics of a vacuum triode.

c) Apply compressed gas insulation and cryogenics to substation equipment.

d) Develop standards for simulated methods and actual field testing of transformers under short circuit conditions.

e) Develop low cost switching devices for operation at EHV and UHV levels.

f) Develop more compact substation equipment for greater capacities, which can be installed in limited space.

g) Develop modular field-assembled transformers.

B. *Tools and Techniques*

1. Shorten the time and reduce the costs of splicing present-day cables.
2. Decrease installation costs by developing improved techniques and equipment applicable to distribution systems and underground and underwater transmission.
3. Develop new and improved tools, techniques, hardware and equipment for the installation and maintenance of EHV and UHV transmission lines.

C. *Aesthetics and Compactness*

1. Design increasingly attractive transmission structures capable of carrying the structural load at reasonable cost.
2. Develop reliable and economical underground equipment, in particular transformers and switching

devices, in order that more distribution components can be placed underground.

D. *System Security and Control*

1. Establish quantitative terms for the security required, continuous quantitative assessment of the state of security of the system by on-line computers, guides for bringing the two into agreement and eventually automatic implementation of corrective measures.
2. Improve present media and exploit new media of intelligence transmission to attain the high quality, capacity and reliability needed for computerized system security and control.
3. Exploit all excitation control for stability; fast prime mover control; fast switching of lines, series or shunt capacitors, shunt reactors and braking resistors for system stability both transient and dynamic; modulation of dc transmission; development of a high-speed phase shifter or equivalent for modulation of ac transmission; and in conjunction with development of energy storage systems, the exploitation of fast control of energy flow for benefit of system stability.
4. Organize system control into an hierarchy for efficient allocation of functions and expand system control to include the analysis of system state, at first on an operator guidance basis leading to an ultimate direct and comprehensive control effort.
5. Advance the science of power system instrumentation for higher reliability, higher resolution, compatibility with telemeter and computer systems, and capability to sense system state variables for computer control. This includes the development of in-service monitoring techniques, particularly for transformers, and new methods of fault detection with higher response speeds.

E. *Test Facilities*

1. Build a high power high voltage industry test facility starting immediately.
2. Expand test facilities for HV and EHV cables and provide for testing dc as well as ac cables.
3. Provide additional test facilities for testing EHV and UHV lines, both ac and dc.

The guiding principles which led to the foregoing transmission and distribution goals are as follows: (1) Provide capacities which are consistent with projected system growth; (2) Continue to improve reliability; (3) Further reduce environmental disturbance and (4) Reduce equipment and installation costs.

PRIORITIES AND COSTS

The recommended total expenditure for research and development in transmission and distribution over the next 29 years shown in Figure 3 and Table III, amounts to $5,770 million. The maximum yearly level of $247 million in later years is a fraction of capital expenditures for transmission and distribution, which today amount to $6 billion per year and by the year 2000 are estimated to be $27 billion per year.

A significant amount of our total expenditures, $3,450 million, is identified as "Present Methods". This work falls primarily into the category of product improvement, the cost of which is expected to be borne in large measure by the manufacturers as in the past. The amount of expenditures for this category is based on our estimate of current expenditures in this area and an assumed growth rate of about 5% per year.

Most of our emphasis has been placed on formulating a program concerned with new methods and components which are listed in seven functional areas: System High Power Test Facility, AC Underground Transmission, AC Overhead Transmission, DC Transmission, Distribution, Bulk Power Substations and System Security and Control. Projected costs for these categories are $2,320 million through the year 2000. Note that for later years an appreciable amount of money is unassigned. We know there will be R&D needs in these years which today we cannot accurately assess and these unassigned costs represent our best estimate at this time.

More detailed tables showing our recommended expenditures through the year 2000 by project and priority are shown in Appendix C to this chapter.

TABLE III

TRANSMISSION AND DISTRIBUTION R&D
SUMMARY OF COSTS TO UTILITIES, MANUFACTURERS, AND GOVERNMENT

(Millions of 1971 Dollars)

Functional Area	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTA
System High Power Test Facility	12.5	17.5	20.0	20.0	15.0	7.5	–	–	–	12.5	12.5	25.0	142.5
AC Underground Transmission	24.2	21.8	22.4	22.9	19.9	18.2	17.9	17.9	17.9	74.6	41.4	44.6	343.7
AC Overhead Transmission	2.3	6.4	10.4	12.6	11.9	9.9	8.1	4.4	3.4	7.4	7.6	1.0	85.2
DC Transmission	7.8	7.8	17.8	16.5	6.6	6.1	5.6	5.6	5.1	24.9	12.3	–	116.1
Distribution	–	3.4	4.9	5.9	6.6	6.1	5.1	5.6	5.6	20.1	19.0	–	82.3
Bulk Power Substations	1.2	1.8	2.0	5.6	6.6	6.8	5.7	5.5	4.6	14.3	–	–	54.1
System Security and Control	2.1	2.7	4.4	4.7	6.4	6.4	6.4	5.4	5.2	16.3	16.3	13.8	90.1
Present Methods	60.0	62.0	65.0	69.0	71.0	73.0	78.0	85.0	88.0	500.0	625.0	1,670.0	3,446.0
Totals	110.1	123.4	146.7	157.2	144.0	134.0	126.8	129.4	129.8	670.1	734.1	1,754.4	4,360.0
Unassigned	–	–	–	–	12	26	33	38	38	243	302	720	1,412
Totals Including	110	123	147	157	156	160	160	167	168	913	1,036	2,474	5,772

R&D GOALS TASK FORCE REPORT TO THE
ELECTRIC RESEARCH COUNCIL, JUNE 1971

TRANSMISSION AND DISTRIBUTION R & D
Distribution of Total Estimated Annual Cost
to Utilities, Manufacturers, and Government

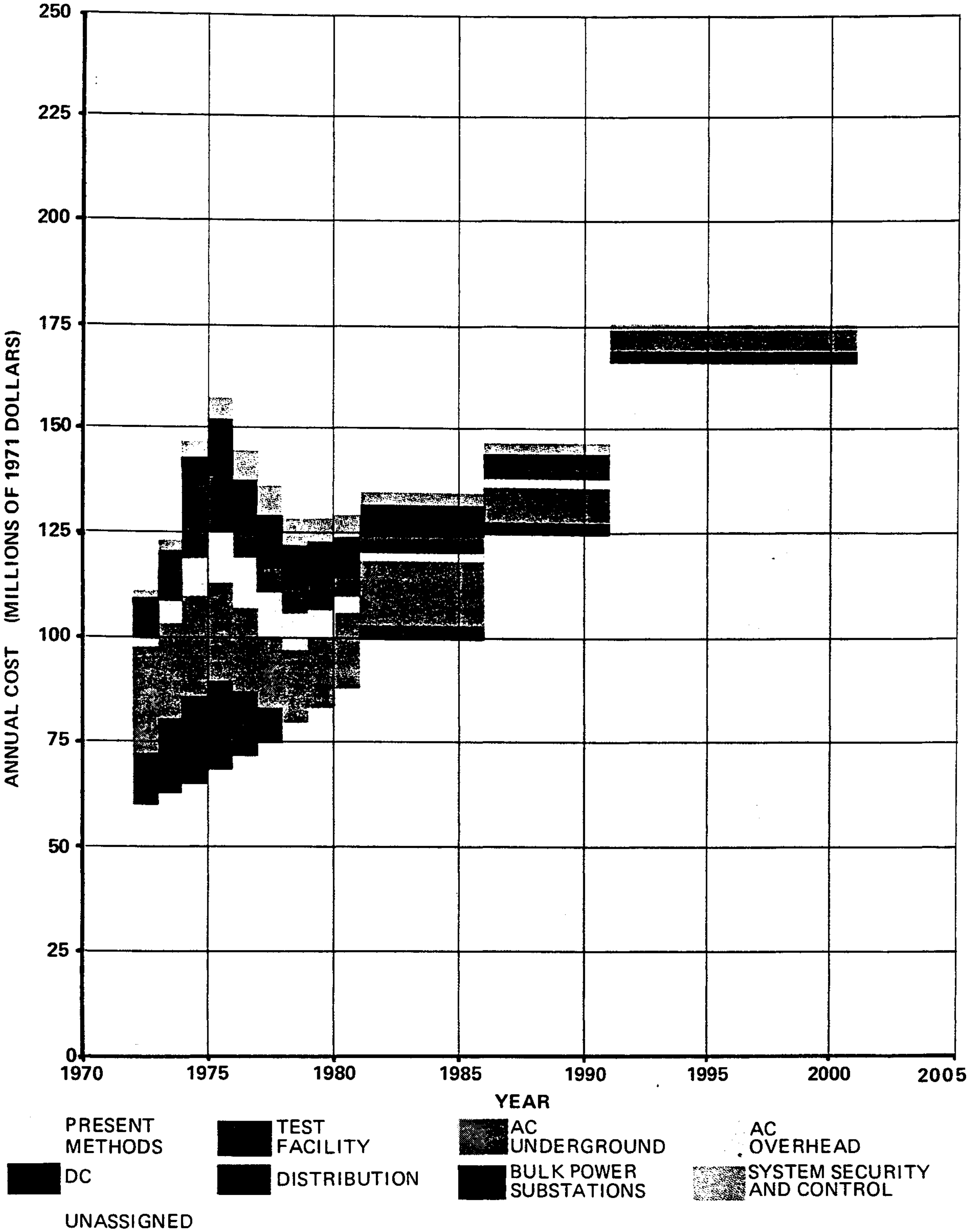


FIGURE 3

R & D Goals Task Force Report to the Electric Research Council, June, 1971

TEST FACILITY

A major priority for research and development, and in fact the one that is listed first on Table III, the summary table of schedules and costs, is the need for an industry-sponsored test facility for high power and high voltage testing, with auxiliary facilities for digital and analog modeling of system problems.

Such a facility does not exist in the United States. It would provide a place for both manufacturers and interested utilities and agencies to test equipment and develop practical knowledge of system behavior. It would also provide a center for power industry technical efforts in a number of fields, and could attract academic interest to an extent far beyond the present levels. Special purpose projects have been conducted at Tidd, Leadville, Apple Grove, Waltz Mill, The Dalles, and Projects EHV and UHV. These should be continued or expanded where appropriate and others started. Other significant research efforts have been conducted at Cornell University, the University of Pennsylvania, the University of Wisconsin and Illinois Institute of Technology Research Institute.

The new industry facility would be only one center, but a very important one among the specialized facilities which now are maintained by manufacturers, colleges and universities, professional research organizations, groups of utilities, governmental agencies and industry-owned facilities. From the standpoint of equipment insurance, the improved performance and reliability of very costly equipment would offset a substantial portion of the investment in this and other centers.

The development of such a facility is a prime industry goal at the present time. The leading candidate is the High Power Test and Research Center proposed at the Grand Coulee site, because it has certain advantages involving short circuit capability and adjacent system facilities. Testing under actual field and live system conditions is an important requirement for the sound development of reliable system components. Many problems in our systems today would have been lessened by the work of such a center ten years ago. We must build a center to attack the problems of the 1980's.

The Electric Research Council is urged to proceed with this project. Any further study of sites, organization or technical operation should take advantage of the work reported in the following three publications:

1. A Proposed Electric Power Research & Development Center, EPRDC Steering Committee, May 1, 1966.
2. Report to the ERC of the Ways & Means Committee, June 10, 1969.
3. The ERC Study of the Proposed HPTRC, by G.R. Corey, October 13, 1970.

The details and justification for our recommended R&D program are presented below for the remaining six functional categories in Table III, that is, AC Underground Transmission, AC Overhead Transmission, DC Transmission, Distribution, Bulk Power Substations and System Security and Control.

AC UNDERGROUND TRANSMISSION

A panel representing the electric utility industry recommended at the 1965 White House Conference on Natural Beauty that further research in underground transmission was urgent. The responsibility for carrying this forward was given to the Electric Research Council's Underground Transmission R&D Program Steering Committee. A year later it adopted both short-range and long-range objectives that were estimated to cost about $17 million over a five-year period.

For the past several years, work has been underway in keeping with the Council's mandate "to carry out a program of research and development of underground transmission systems in recognition of the need for less costly installations and for systems of higher voltage". This remains the present and future aim of efforts within this area.

In addition to projects sponsored by the Council, some work has been carried out by private industry. Notable efforts include the development of compressed gas insulated cables, research on a synthetic paper to replace cellulose paper, and development of extruded dielectric cable. Because of the size of these tasks in relation to the resources of individual companies, these efforts will benefit from vigorous utility industry support.

Among the accomplishments of the Council's program is the construction of a test station at Waltz Mill, Pa., by the Westinghouse Electric Corporation under contract to the Edison Electric Institute. Opened in May, 1969, this station is the largest of its kind in the world with a voltage capability of 1100 kV. Currently, 500 kV paper-insulated cables and 138 kV extruded dielectric cables are being subjected to tests that will simulate an expected service life of 40 to 50 years. Other new concepts will be tested as they develop.

There is opportunity for savings resulting from improved techniques for external forced cooling of present-day cables. In the next several years this will be important because expenditures will be greater for systems at 138 or 230 kV than they will be for extra-high-voltage systems. Research into the design and economic advantages of these techniques indicate that, in general, the capability of pipe-cable circuits can be as much as doubled if a low-viscosity type pipe oil is used as the pressure medium in force-cooled cable lines.

Present cable splicing techniques require critical environmental control and around-the-clock work schedules for long periods. Research will be directed toward simplification in order to cut both time and costs. Simplified jointing would ease the shortage of technicians and would likely eliminate the need for air-conditioning of manholes during the jointing operation. The time saved also would help speed restoration of service after EHV cable faults.

Necessary to the development of higher capacity pipe-type cables is a better type of insulation than is now available. Research is being aimed at methods of making a synthetic paper with more desirable electrical characteristics, and with impregnation and physical properties somewhat similar to those of cellulose paper, for use in pipe-type or self-contained cables.

A cable using only gas as the major insulation is a rapidly developing concept. Industry-sponsored research is aimed at testing the behavior of compressed gases under simulated cable operating conditions. Results have indicated that free-conducting particles are a major factor in reducing the insulating strength of an otherwise ideal gap, and have demonstrated the benefits of electrostatically removing conducting and semi-conducting particles from the active insulating portion of the system, and of providing a dielectric coating over the central conductor.

Because electrical conductivity increases markedly at low temperature, cryogenic systems are attractive. High purity aluminum is ten times as conductive at liquid nitrogen temperature as it is at room temperature, and 500 times as conductive at liquid hydrogen temperature. A project now underway is aimed at developing a cable design which uses cryogenic cooling to operate at temperature levels of 20-100 K. Work so far indicates this kind of cable might be used in the range of 2000 to 5000 MVA. Liquid hydrogen cables appear to be more difficult to develop and require more precautions in handling, despite an apparent cost advantage, than do liquid nitrogen cables. So for the time being the latter are preferred. A demonstration-size model has been constructed and tested. Based on progress to date, a commercial version can be available in the mid-1980's.

With cable systems in view, a preliminary study has indicated that superconductivity is theoretically feasible for ac power transmission. Measurements made of the ac losses in pure niobium conductors of a size and shape suitable for practical power cables show that at liquid helium temperatures the amount of the losses is adequately low. It still must be demonstrated that the dielectric behavior of compressed liquid helium will be satisfactory. But since the measurements were sufficiently encouraging, an economic analysis was made and this indicates that substantial savings over today's costs may be obtained for systems that will in the future require capabilities of 2000 to 10,000 MVA.

To date, research has been limited to seven projects because of lack of funding beyond the approximately $8 million authorized by EEI and the Electric Research Council. The underground power transmission research program which is proposed to meet both short-term and long-term needs of the industry includes projects in the following areas:

Test Facilities
HV and EHV Cable Systems
Cryogenic Cable Systems
Methods of Ambient Control
Basic Studies
Installation Methods
Cable Accessories
Materials Development

The day of simple, reliable and economical transmission of great blocks of power for long distances underground is quite far in the future. Considerable research will be required to meet this goal, both to build on what has been begun and to enter new areas.

Among the areas of importance are:

To develop methods of reducing installation cost. This will include studies for detecting, measuring and mapping underground obstacles, studies of guided boring operations to replace trenching, investigation of new methods of pavement cutting and studies of improved methods of underwater installation.

To develop a three-phase gas-insulated cable. A design employing a common enclosure should offer significant economic advantages over present-day isolated-phase systems and may offer cost advantages over conventional pipe-type cables.

To develop high voltage extruded dielectric cables. They might well prove to be simpler, less expensive and less troublesome than conventional, oil-impregnated-paper insulated cables.

To determine the feasibility of advanced concepts of underground transmission so that the industry may take advantage of any breakthrough, including a study of the transmission of microwave power.

The complete program must go far beyond the task of simply examining the technical feasibility of, for example, superconducting underground transmission and deciding whether or not it merits support as a research endeavor. The problem is a more general one. Decisions must be made on what methods or combination of methods, involving all aspects of underground transmission, will lead to more economical transmission of power in the immediate future and in the long-term future. All categories of costs must be taken into account: acquisition of rights-of-way, if required; capital costs of the cable and accessories, installation problems and costs; operating and maintenance costs. Any additional costs involved in attaching the cable system to terminal stations or to an overhead transmission line also must be included.

AC OVERHEAD TRANSMISSION

Our most reliable and economical means of transferring large blocks of power within a power system, between power systems, and between geographical areas continues to be ac overhead transmission. With increasing reliability, it has become possible to transmit larger blocks of power without a corresponding increase in space requirements or in cost.

Because of the efforts of utility companies and manufacturers, through such projects as Tidd and Leadville in the early 1950s and Apple Grove in the early 1960s, transmission voltages are now common at 345 kV. Continuing efforts in the early and mid-1960s at Apple Grove and at Project EHV at Pittsfield have made possible 500 and 765 kV systems.

Recognizing the need for even higher voltages for transmitting larger blocks of power, Project UHV (RP-68) was initiated by the Edison Electric Institute in 1964 with subsequent participation by the ERC and BPA. Almost $5 million has been made available for this project through 1971, and nearly $900,000 for 1972. This project is intended to demonstrate the feasibility and resolve the problems of voltages in the 1000 to 1500 kV range.

In 1965, the concern over improved appearance of utility facilities resulted in Research Project RP-75 which was aimed at the development of aesthetically acceptable overhead transmission structures. The current widespread use of ornamental pole structures in the industry is evidence of the public's acceptance of the designs which were developed; for example, one design developed by a large utility company was given an award in 1968 by the American Institute of Architects.

We see the need not only for higher voltage levels, improved appearance, and better utilization of land, but also for the solution of problems at present voltage levels, such as corona, noise, conductor movement, and insulation.

The objective of this section is to describe the goals and projects necessary to the expansion of overhead transmission facilities which we know must occur, in view of the projected increase in demand for electric power. Overhead transmission will certainly continue to be a major means of transmitting this power to the points of distribution. Undergrounding draws vigorous support, and R & D on high voltage cables must continue, but the staggering cost ratio to overhead transmission may never be overcome without a fortunate breakthrough, perhaps by materials engineers.

Reliable, safe, and low cost ac overhead transmission must be expanded in such a way to insure public acceptance, with minimal impact on the environment, and without a proportionate increase in right-of-way requirements.

To accomplish our goals, it will be necessary to continue on a long range basis Project UHV (RP-68) to study the feasibility and economics of voltages above 765 kV, and select an industry standard for the next voltage level.

Transmission structures must be developed further and designed better so that installed costs may be reduced. Work on RP-75 aesthetic design of transmission structures should be continued to develop aesthetic, yet realistic and practical designs.

Methods of eliminating or controlling conductor movement – galloping, vibration, and subconductor oscillation – should be developed. Design parameters for multiconductor bundles are needed, and the current carrying capacity of conductors must be further improved.

Insulation improvement requires design criteria for minimum electrical clearances under extreme operating conditions such as emergency loading, high wind, and galloping conductor conditions. We also need to improve insulation systems and methods of cleaning insulators in areas of high contamination.

We need to study the effects of electromagnetic and electrostatic induction and corona at UHV levels, including audible noise, radio and TV interference.

New methods of grounding are needed for areas with high ground resistances requiring deep ground rods or counterpoise. The size, material, configuration and uses of overhead ground wires need to be studied and improved.

DC TRANSMISSION

Although we have the capability to build a point to point dc transmission line, much refinement and operating experience of this new technology with its novel hardware is required. In addition to conversion equipment improvement, the areas of UHV overhead lines, dc cables and breakers require major development efforts.

As an ERC research project, the existing testing facilities at The Dalles will be upgraded for evaluation of overhead dc transmission up to ±600 kV. Emphasis will be placed on studying the effect of contamination on flashover strength of insulators and on further evaluation of corona and associated interference problems. The goal is to provide design parameters for transmission lines with capacities up to 2000 MW.

To design dc transmission lines with capacities equivalent to ac voltages up to 1500 kV, further basic work is required to evaluate insulation requirements, physiological and psychological effects of UHV dc fields as well as such factors as audible noise, radio and telephone interference factors connected with corona discharges through the range from ±750 kV through ±1500 kV.

Perhaps a new family of cables will have to be specifically designed for dc applications because of the fundamental differences in electrical stress distribution between dc and ac cables. An evaluation should be made on the degree of stress inversion with temperatures for different insulation materials, and it is important that the effect of harmonics should be further evaluated. This effort should also assist in determining the capability of present ac cable designs for dc application. If harmonics have no serious effect on dc cable, it may be possible to eliminate harmonic filtering on dc lines that are entirely underground.

Improvements are needed in present day converter equipment. Research is required to solve the arc-back problem with mercury arc converters. Although solid state converters (thyristors) are not thus afflicted, we need to reduce the number of components in a solid state valve and lower the cost. What we also need for the future is a converter element with the turn-on/turn-off characteristics of a power transistor. The large amount of peripheral equipment such as ac and dc harmonic filters, reactive compensation and valve damping circuits must be minimized and optimized.

Space is always a problem. To make dc transmission useful in terms of the injection of large blocks of power into the hearts of urban power systems, converter terminals must be miniaturized. Solid state valves promise appreciable reduction in space as well as in what is required for valve damping circuits. But they provide little reduction in the space required for ac and dc filters and reactive power compensation.

All present dc transmission lines are two-ended systems, in which the terminals control the power flow and interrupt faults. But if dc transmission lines are to be widely applied, and if they are going to be tapped, successful dc circuit breakers must be developed. Conventional circuit breaker technology cannot be applied to these systems. Currently, a second phase of an ERC project at the Hughes Research Laboratory is underway to develop a dc breaker. But even if the program is fully successful, all breaker requirements may not be met. More research on different breaker concepts may be necessary.

More knowledge is needed about the role of dc transmission in integrated ac networks – in other words, how the whole system will work together. Instead of constant power corridors, more sophisticated controls will make possible the use of dc lines as controllable dampers during system distrubances. Studies of this sort can be conducted on digital computers, on model systems (which has been done to a limited extent by EEI RP-56) and on trial installations within actual power systems. The most effective approach would be to install a dc transmission system as part of an existing ac network, scaled in such a way as to be a significant part of the ac system while at the same time superfluous to its needs. It would also be a test site for various converter elements, dc breakers, control schemes, filter designs and other associated equipment.

DISTRIBUTION

Increasingly, distribution must go underground in both urban and suburban areas. Reliable and economical underground equipment, especially transformers and switching devices, is needed to accomplish this goal. Also needed is a larger and better coordinated R&D program than the present level of effort by manufacturers and individual utilities – in short, an industry-wide program.

High on the list of needs are low-cost, long-life, direct buried distribution transformers and capacitors for URD application. One promising concept is the dry type, solid-state capacitor.

Switching and protective equipment of high capacity and reliability also must be developed for underground as well as for higher voltage overhead distribution systems. In the short range, this requires work on current limiting fuses and higher capacity compact switches. In the longer term, we must investigate the feasibility of circuit interruptors with no moving parts and solid-state current limiting circuit breakers.

Underground cables are now installed and maintained with the use of standard equipment and techniques. Nevertheless, improved trenching methods as well as techniques for tapping energized primary cable safely are required in order to obtain fast, low cost installation and maintenance of underground cable systems.

The development of smaller and more compact high capacity substation equipment will improve the acceptability of substations in urban residential areas.

Increased efficiency and reduced cost for the complex distribution system of the future will result from the development of automated data collection and control of substation and field devices. Necessary will be the development of remote meter reading, data logging, alarm and control systems, as well as an economical communication system.

The influence of environmental factors also must be studied. We need more information about corrosion resistance, heat dissipation and moisture migration, and in the overhead area we need to develop contamination resistant insulators and tree growth inhibitors which are ecologically safe.

Our knowledge is still meager concerning the problems caused by lightning and other surges on the distribution system. Complete investigation of lightning protection including the correlation of theoretical calculations and field experience is required. Also, one of the important elements in improving system performance is to develop economical low cost grounding and to determine the effects of transient voltages and current on solid-state equipment.

Economical, high-voltage (138 and 230 kV) power class transformers with an improved ability to withstand secondary short circuits and surges due to ferroresonance are needed, as well as more reliable and compact tap changers using nonflammable insulating media.

A quiet, economical, reliable and safe distribution transformer should be developed for installation at or in the house (not for direct burial), which should have the ability to provide constant voltage and flicker correction either built into the transformer or added as a separate module. This would circumvent all the existing problems of various transformer installations and provide automatic control of voltage at each home with more reliable service.

Finally, in the area of distribution system design, conceptual type dc systems should be developed and the problems of higher ac utilization voltages for residential customers should be studied.

BULK POWER SUBSTATIONS

Manufacturers have traditionally taken the responsibility for supporting research for substation equipment, while users have been responsible for indicating the developments needed and applying and testing the new equipment in their systems. To make sure the necessary research and development is carried forward, it is clear that a stronger industry position is required. On a national basis, this should include both the provision for system-oriented test facilities and coordinated basic research in areas such as materials and systems analysis.

The size of transformers is a major drawback to the effort to provide increased system capacity; they are becoming too large to ship and are too difficult to rebuild when failures occur. Development should center on the concept of modular design, making use of the building block technique. Special materials and cooling methods also should be developed which, by greatly reducing heat and losses, would permit more compact transformer designs.

Another substantial question is the short circuit capacity of present transformer designs. The higher capacities and lower impedances of the future will create increasingly critical problems. Prototype testing indicates the need for a system-connected industry test facility, which could lead to development of standardized, simulated methods for factory testing.

Major capital investments in the utility system and the damage incurred in equipment during short circuits require the development of low cost "on-line" devices to detect possible weak links in system apparatus. They should monitor, for example, generated gas, corona, RI signals and sonic waves. In-service voltage transducers require substantial research and development work.

New methods of fault detection to provide faster and more reliable system protection should receive substantial support. Industry aims should include the development of a system making use of line surge impedance measurements or of a system whereby line end equipment provides continuous on-line pulsing which is tripped by any minute change. Development of half-cycle relaying and its coordination with one-cycle or faster breakers should receive emphasis.

A useful systems concept would include the measurement, decision making, relaying and breaking functions as a single unit with the aim of decreasing clearing times. Special equipment for each function will have to be developed. Faster and more reliable communications channels between station terminals also are needed for relaying and control.

Lower cost protective and utilization equipment should be developed to allow industrial plants to ride through momentary disturbances on power systems without interruptions to service. Research work in the representation of induction and synchronous motors and their controls would be required, so that industrial plants could be adequately represented in computer studies and their voltage dip characteristics predicted under various operating conditions. This would assist the design of appropriate protective devices. Motors that run at unity or leading power factors may be desirable.

A major factor in the increased cost of stations is the problem of adequate station insulation. Substations, in common with other parts of our system, will be aided by the development of improved insulating materials and the development of improved lightning arresters.

Little basic knowledge is available on the probability of lightning strikes where multiple shielding wires and masts are used. Investigation should be made of better station grounding schemes which provide short circuit dissipation and personnel safety, and eliminate transients in control systems. A concentrated effort should be made on obtaining a better theoretical understanding of grounding parameters.

The development of a single large capacitor to replace the present "stacked cans" would be useful in order to reduce maintenance and simplify protection. Reliability study techniques should be used further to analyze substation layouts and equipment.

A system of transient-free circuit breakers utilizing automatic pre-insertion impedance devices is needed in order to provide greater fault interrupting capability. Such a breaker would lower the level of fault current interrupted and change the system power factor to unity, to allow interruption at a current and voltage zero. Also, breakers that interrupt at current zero, thereby reducing the duty on the interruptor and causing less disturbance on the system would be beneficial.

The high cost of circuit breaker maintenance also needs attention, particularly that associated with auxiliary equipment such as gas carts, compressors and oil handling equipment. Therefore, development of vacuum, puffer-gas type or minimum oil breakers should proceed. Development of breakers with no moving parts could well utilize solid state technology, with particular emphasis on reducing the in-service voltage drop across the devices.

Other circuit interrupter developments which would be useful include: Low cost devices to switch EHV shunt reactors and automatically place them in service for transient or steady state system conditions, devices for switching line capacitance or shunt capacitors at high voltage and extra high voltage levels, and higher voltage and higher interrupting capacity metal-clad switchgear that does not require auxiliary gas handling systems.

Higher generator voltage can reduce the need for increased bus sizes. Development should proceed on generator buses using cryogenic or water cooled principles. Research can develop data on the effects of direct short circuiting of full sized generators, rather than using calculation or model test techniques.

Cryogenic and superconducting technology should be developed and applied in order to reduce the size of transformers, synchronous condensers, and motors. Sophisticated in-service monitoring devices would help boost service reliability.

The significance of safety and physiological effects related to EHV and UHV voltage levels should be further investigated. Research in methods can be used to determine any shielding requirements that may be necessary. This area of research is discussed in the Chapter on Environment.

Noise also becomes an increasingly critical consideration, as more sites are required for installation of large substations and of other facilities such as gas turbine units. We need to improve noise suppression and make the substations less obstrusive from an aesthetic viewpoint.

SYSTEM SECURITY AND CONTROL

Research on behalf of more reliable, economical system security and control must be done in three broad areas. The inherent dynamic characteristics of all system components, including loads, must be identified accurately, and they must be accommodated appropriately in power system development. Technology must be developed for the collection of data from the power system which can be converted into system state and control information. The dynamic influences must be exploited, through control, for maximum system benefit.

Our goals, then, are to achieve high inherent transient and dynamic stability; to augment this through control; and to refine and automate the manipulation of system power interchange and system preservation measures.

The requirements for system security and the techniques for achieving it are changing rapidly. System loads are rising fast. Systems are becoming increasingly interconnected. Pressures toward economy must be reconciled with the need to maintain adequate margins of security.

Need for attention to system security was emphasized by the Northeast power failure of November 1965. As a result, a broad research effort was launched, and analytical techniques for the assessment of security are beginning to emerge. The security assessments and relief plans serve as guidance for the system operator; implementation is largely manual.

We need to develop methods for quantitative assessment by on-line computers of the actual security state of the system for comparison with the desired state. Then there must be guides for bringing the two into agreement. Eventually the implementation of corrective measures might well be automatic.

Highly important to the achievement of advanced security and control will be the ability to transmit, with great reliability, vast quantities of intelligence. This will take into consideration all forms of communication:

voice, teletype or equivalent, digital data channels, and video. Since the function of intelligence transmission affects the success of all the other functions discussed in this section, its importance cannot be subordinated. Present media of communications – wire, radio and microwave – are nearing the saturation point in many cases. Work must be done to improve present methods and to exploit new ways of intelligence transmission, so that the high quality, capacity and reliability needed for computerized system security and control may be attained.

System stability is of utmost importance to system security. It takes into consideration both transient and dynamic behavior of power systems as they are influenced by inherent characteristics and by high-speed control.

Various measures for improving power system stability are known, but more research is needed. For example, computational techniques for analyzing dynamic stability need further refinement to permit more extensive analysis of system dynamics for design purposes.

The extent of exploitation of presently known measures for improving system stability by control is small. Potential gains are high, while the relative cost of a given improvement by means of control is small compared to an alternative means of improvement, such as reduction of impedance. In fact, for economic reasons, higher impedances are being accepted. Generator inertia is an important aid to system stability, but in new designs economic pressures are toward reduction of inertia.

In the immediate future, efforts and accomplishments in system dynamics by control should be expedited to offset the adverse influences of economy upon impedance and inertia.

The improvement of power system control is one of the most important ways of assuring an adequate, reliable and compatible supply of power. In addition to its recognized function of manipulation of generation and load flows to satisfy loads, control makes possible system security and much of system stability, with the help of intelligence transmission and instrumentation.

As progress is made toward computerized control, we need to establish a measure of controllability and criteria for the degree of control required. System control must also be organized in terms of an efficient allocation of functions to the respective stages, and expanded to include the analysis of system state, beginning on the basis of operator guidance and leading ultimately to direct and comprehensive control effort.

Though instrumentation is auxiliary in relation to security and control, it is a vital link in the chain. Power systems have become so complex as to tax the capacity of the human operator to handle all the detail. Computer control offers the capability of processing large volumes of data, rendering guides to system operators, and initiating action. But this requires a higher level of reliability, resolution, and, still more important, an output which can be readily interfaced or accepted directly by computer systems. Moreover new varieties of instrumentation such as system state variables are needed to implement new and developing concepts in this field.

CHAPTER 4

ENVIRONMENT

It must be recognized that every activity of man causes some intrusion on the environment. It must also be recognized that the quality of life in the world has improved with the increased use of energy and that man will not turn back in his quest for an improved life even as he becomes more aware of the problems that confront him in satisfying his ever-increasing need for energy.

The policy of the electric utility industry in the United States is to satisfy this increasing demand with minimum intrusion on the environment and in a manner that will allow for provision of an adequate, economic and reliable power supply for the country. This policy becomes our main environmental goal.

SPECIFIC GOALS

In establishing the goals in the area of environment, we have been concerned with the prevention of acute and chronic environmental effects, efficient utilization of resources and preservation of comfort and enjoyment. These considerations are reflected throughout the environmental R&D program.

The environment and environmental controls and effects touch on every aspect of utility practice. Many such aspects are dealt with in other sections of this report. For example, projects concerning more efficient power generation, although they would decrease air contamination and thermal effects per unit of power produced, are not included in this section but, rather, are covered in the section on energy conversion. Cryogenic cable development is dealt with in the chapter on transmission and distribution, even though undergrounding is an environmental consideration. Other examples include coal gasification (energy conversion), alternate cycles (energy conversion), aesthetic tower configuration (T&D), and waste heat use (utilization).

In this chapter we have assembled an additional set of 22 specific R&D goals and 71 specific tasks which in many cases are an extension of existing R&D programs and relate exclusively to the environment. These 22 goals, which fall into four broad categories of air, water, nuclear and general, are:

Air Quality

1. Determine basic physical and chemical data related to removal processes for particulates and oxides of sulfur and nitrogen from stack emissions.
2. Further improve systems to restrict

SO_x emissions in present and future power plants.

3. Further improve systems to restrict NO_x emissions in present and future power plants.
4. Further improve systems to restrict particulate emissions for new and retrofit operation.
5. Develop a feasible process for desulfurizing coal and oil fuels.
6. Determine health effects of short-term, high-concentration exposures to oxides of sulfur and nitrogen, particulates and sulfuric acid.
7. Determine the effect of major constituents of power plant effluents on vegetation.
8. Study the synergistic effects of the major stack gas constituents in the atmosphere.
9. Develop standarized portable measuring instruments for the measurement of low concentrations of oxides of nitrogen and sulfur and particulates.
10. Determine the distribution and effects of minor constituents of stack emissions.
11. Improve dispersion technology.
12. Study effects of alternate cooling systems.

Water Quality

1. Investigate effects arising from disposal of solid and liquid wastes from power plant operations.
2. Determine the effects of once-through cooling systems on aquatic biota.
3. Develop viable alternate methods of cooling heated water discharges.
4. Evaluate the effects of heated water discharges on the health and aging of aquatic ecosystems.

Nuclear

1. Further reduce radiation release from the overall nuclear cycle.
2. Determine cumulative effects of small amounts of radioisotopes on biological systems.

General Environment

1. Determine the health effects of exposure to electromagnetic and electrostatic fields.
2. Develop siting criteria on a regional basis for fossil fuel and nuclear power plants.
3. Develop methods of noise control and noise specifications for power plant equipment.
4. Develop ecosystem and climatological model to predict long-term effects caused by power generation.

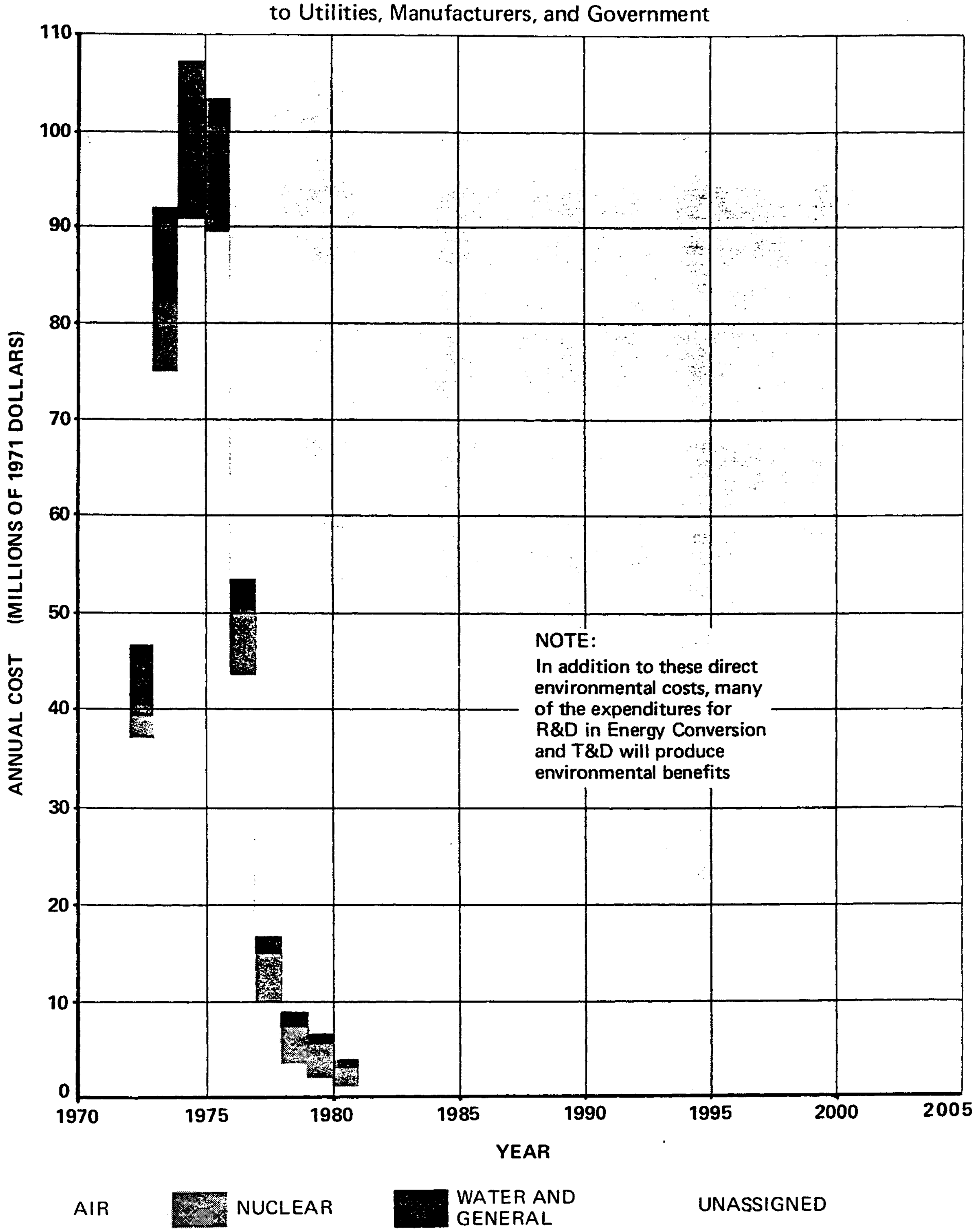
PRIORITIES AND COSTS

As noted earlier, these 22 goals are divided into 71 specific tasks. Figure 4 shows the distribution of estimated costs for environmental R&D. Table IV shows the environmental R&D effort together with its suggested priority ranking, time table and estimated costs. Apart from the environmental implications of R&D spending recommended in other chapters of this report, to accomplish just the environmental tasks set forth in this chapter will require R&D on the order of $100 million per year for the foreseeable future. The unassigned area encompasses expanded funding for the long-range projects listed in this report, for projects related to aesthetics, for unforeseen problems arising from advanced conversion techniques, for problems arising from the need to limit emission of other fossil combustion products and environmental effects related to underground or undersea siting.

ACHIEVING GOALS

The environmental consciousness of the

ENVIRONMENTAL R & D
Distribution of Total Estimated Annual Cost
to Utilities, Manufacturers, and Government



R & D Goals Task Force Report
to the Electric Research Council,
June, 1971

FIGURE 4

TABLE IV

ENVIRONMENTAL R&D

SUMMARY OF COSTS TO UTILITIES, MANUFACTURERS, AND GOVERNMENT

(Millions of 1971 Dollars)

Priority	Project	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 2000	TOTALS
1	Air Quality:* 1] SO_x, NO_x and Particulate removal 2] Saline water cooling towers 3] Desulfurization of coal 4] Trace elements in stack gas	24.4	54.6	65.8	49.1	16.3	1.5	–	–	–	–	211.7
	Water Quality: 1] Biological effects of heated water 2] Effects of entrainment of organisms in cooling water 3] Intake structure design	4.9	6.2	2.4	2.2	1.9	0.5	0.5	0.5	0.5	0.5	20.1
	Nuclear† 1] Tritium removal 2] Removal [99+%] of radio-iodine	1.4	6.7	10.9	7.2	2.3	1.0	0.8	0.5	0.2	0.1	31.1
	Subtotal	30.7	67.5	79.1	58.5	20.5	3.0	1.3	1.0	0.7	0.6	262.9
2	Air Quality: 1] Synergistic effects of SO_x, NO_x and H_2SO_4 2] Stack gas interaction with cooling tower plumes 3] Fate of stack gas constituents 4] SO_x and NO_x measuring devices	8.7	17.7	23.9	37.2	23.9	5.7	0.1	–	–	–	117.2
	Water Quality: 1] Alternate methods for cooling heated water discharges 2] Prediction of effects of heated water discharges	3.0	3.2	0.5	0.9	0.9	0.8	0.7	0.5	0.3	0.2	11.0
	Nuclear: 1] Fate of radionuclides 2] Safe long-term storage of radioactive gases	–	0.3	0.5	0.5	1.1	1.4	1.5	1.5	1.1	1.1	9.0
	General: 1] Development of siting criteria 2] Noise control	–	0.2	0.2	0.2	0.2	0.2	0.05	0.05	0.05	0.1	1.3
	Subtotal	11.7	21.4	25.1	38.8	26.1	8.1	2.4	2.1	1.5	1.4	138.5
3	Air Quality: 1] Theoretical studies of stack gas constituents 2] Effects of stack gas on vegetation 3] Modeling of evaporative cooling systems and stack gas emissions	0.8	0.8	0.8	1.6	2.1	2.6	2.3	1.2	1.0	2.8	16.0
	Water Quality: Long-range studies of the effects of heated-water discharges	–	–	–	0.2	0.2	0.1	0.1	0.1	0.1	1.1	1.9
	Nuclear: 1] Methods of decommissioning plants 2] Evaluation of radiation effects from AEC data	–	–	2.3	2.8	2.8	2.3	2.3	1.3	1.3	3.8	18.9
	General: Noise specifications for power plants	–	–	0.1	0.1	0.1	0.1	0.1	0.03	0.03	0.3	0.9
	Subtotal	0.8	0.8	3.2	4.7	5.2	5.1	4.8	2.6	2.4	8.0	37.7
4	Air Quality: Miscellaneous theoretical studies of effects of stack gas	3.5	1.7	1.0	1.2	1.5	0.5	0.5	0.5	0.3	–	10.7
	Water Quality: Long-range biological studies not necessarily dealing with effects of power plants	–	–	–	0.1	0.1	0.2	0.2	0.2	0.1	1.1	2.0
	General: 1] Long-term effects of power plants 2] Effects of CO_2 3] Effects of electromagnetic fields	–	–	–	–	0.1	0.1	0.1	0.1	0.1	1.0	1.5
	Subtotal	3.5	1.7	1.0	1.3	1.7	0.8	0.8	0.8	0.5	2.1	14.2
	TOTALS	46.7	91.4	108.4	103.3	53.5	17.0	9.3	6.5	5.1	12.1	453.3
	Unassigned	–	–	–	–	50	90	100	100	100	2000	2440
	Totals Including Unassigned	47	91	108	103	104	107	109	107	105	2012	2893

†These Nuclear figures supplement government expenditures related to nuclear power.

*The cost now being incurred by many utilities in the development of various SO_x and NO_x control systems has not been included in the estimates of these tasks.

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE, 1971

electric power industry is growing. It dates back many years when it first manifested itself in aesthetic designs of lines, substations, power plants and offices, and emission control. Later, it turned to improved emission control, increasing undergrounding, provision for recreation and the like. Today the industry operates on an expanded level of environmental consciousness that dictates the above-stated environmental goals and tasks.

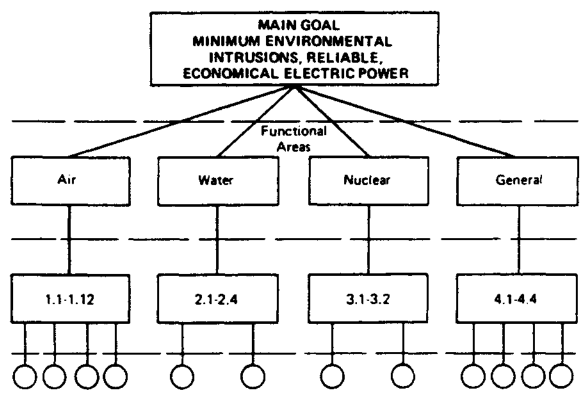
To accomplish these goals, we recommend that an expanded environmental organization under the auspices of the Electric Research Council be formed without delay. It should be part of the ERC Research Institute called for in Chapter 8 to oversee the total R&D effort called for in this entire Report. The primary purpose of the reconstituted environmental organization would be to coordinate and carry out environmental R&D to achieve the stated goals in cooperation with electric utilities, governmental agencies and manufacturers.

The complications involved in deciding what organizations are to perform what tasks are tremendous. The manpower requirements, alone, imply that no one or even several organizations could handle the job. It will be necessary to have assistance from industrial organizations, university research groups, private research groups, various government agencies and, of course, the utilities themselves. We must look to the universities to train the necessary manpower.

How do we get the most for our environmental research dollar? An illustration of the complication is shown in Appendix D, which contains a fairly representative statement of the state-of-the-art in the areas listed in our goals. A complete state-of-the-art compilation would have run into thousands of pages and hence the necessity of abridgment into representative projects. One bibliography dealing with effects of heated water on fish ran to 1870 entries. This illustrates the specialization that knowledge in the environmental area has undergone. With a view toward obtaining the most for our research dollar, a tremendous effort will be required in the selection and design of task work. From a practical standpoint, the work will have to be coordinated with on-going efforts in the Air Pollution Control Office, Federal Water Quality Administration, Environmental Science Services Administration, the universities and the private sector in order to avoid overlap of investigation and to properly dovetail our R&D program.

JUSTIFICATION OF GOALS

We believe the 22 goals listed at the beginning of this chapter are broadly representative of our industry's needs in the area of environmental R&D, although we recognize they are not all-inclusive. Generally, they are designed as steps to take us from today to a desired future condition. Justification for each goal follows the chart below which divides the goals into functional areas and decimal listing.



AIR QUALITY

In general, the goals in this section relate to the health effects of stack effluents and control methods for stack gas constituents. Starting at today's state-of-the-art, we can project the kind of air quality desired. These goals, then, are designed as steps to take us from today to a desired future condition.

1.1 *Determine basic physical and chemical data related to removal processes for particulates and oxides of sulfur and nitrogen.*

In an engineering sense, it is not, strictly speaking, necessary to know the intimate details of a chemical reaction or the theoretical basis for the charging of a particle in an electrical field. The very fact that a process works allows us to make use of it. However, a detailed knowledge of the basic theoretical chemical and physical principles provides a basis for further improvement of the process or processes involved. This goal is designed to make available the detailed theoretical and experimental information related to reaction kinetics, thermodynamics and physical chemistry of removal processes in order that a better understanding of them can be achieved.

1.2 *Further improve systems to restrict SO_x emissions for use in present and future power plants.*

Sulfur oxides result from the combustion of fossil fuels, primarily coal and oil. The sulfur in the fuel, which may be in either the organic or inorganic state, reacts with oxygen from the air to form, chiefly, sulfur dioxide. Undoubtedly, one of the largest and most serious problems that will confront our industry for the next decade is the problem of removing or restricting the emission of oxides of sulfur from stack gases. This restriction will be necessary not only for new plants but also for older plants. Although economics may dictate the use of low sulfur fuels for older plants with lower load factors, it is a virtual certainty that there must be developed a reliable and economic method for the removal of oxides of sulfur from stack gas.

Research must be performed both for the regenerative and throw-away systems including a determination of the relative merits of different types of gas-liquid contactors, sulfur-loaded absorbents and the economics of disposal of waste products as well as the most feasible form of sulfur to be recovered. However, because of the abundance of current projects concentrating on throw-away systems, we have limited our designation of tasks to development of regenerative systems.

1.3 *Improve systems to restrict NO_x emissions for use in present and future power plants.*

The oxides of nitrogen [NO and NO_2] are produced by combustion processes in which oxygen and nitrogen from the air combine to form chiefly nitric oxide [NO]. Nitric oxide reacts slowly with more oxygen to form nitrogen dioxide. As with oxides of sulfur, the need for restricting the emission of oxides of nitrogen is virtually a certainty. Unlike oxides of sulfur, certain operating variables have an effect on formation of these gases. Research must be conducted on the effects of these variables, such as boiler configurations, temperatures, excess oxygen as well as on development of removal schemes. The NO_2 portion of the gas will probably be removed by an alkali scrubbing system, however, only a small portion of the total is in the NO_2 form. Research must be conducted on catalytic oxidation or additives to form NO_2 for easy removal. Further, several of the second generation methods have been cited in the literature as removing both NO and NO_2 as well as oxides of sulfur. The most feasible of these processes should be funded in order to develop one process for removal and recovery of sulfur and nitrogen compounds rather than two distinct processes for the removal of these gases.

1.4 *Improve particulate emission restriction systems for new and retrofit operation.*

Utilities have been removing particulate matter from stack gases at increasing efficiencies for decades, utilizing electrostatic precipitators (EP) with a design removal efficiency of 99.6 per cent and they may seem to need very little improvement.

As we learn more about the effects of particles on humans, it appears that particle size can play an important role and that sizes below 1-2 microns may be the most serious in terms of health effects. These are precisely the type of particles least susceptible to removal via EP and mechanical dust collectors. Another problem with the EP is the inability to produce consistent results in the presence of ash from low sulfur coals. The high temperature EP does a better job in this area wherein performance is almost independent of coal sulfur content at operating temperatures near 600°F. Thus, we must study not only processes central to the EP, but also investigate alternative methods for removal of particulate matter from gas streams.

1.5 *Develop a feasible process for desulfurizing coal and oil fuels.*

It appears now that the means of sulfur removal used in a given situation will depend upon the particular features of the plant involved. For older plants with relatively low load factors, an attractive alternate to removal of oxides of sulfur from stack gas is to use a low sulfur fuel. Since the economic availability of this type of fuel is low in many parts of the country, research is needed to produce low sulfur fuels from high sulfur fuels. Among the methods that must be investigated for coal are froth flotation, dry centrifugation and solvent refining.

For fuel oils, the technique of hydrodesulfurization offers promise as a method for sulfur removal; however, research on more effective, longer-lived, less easily poisoned catalysts is necessary.

1.6 *Determine health effects of short-term, high-concentration exposures to oxides of sulfur and nitrogen, particulates and sulfuric acid.*

This goal is a continuation of the work being carried on at Hazleton Labs under EEI RP-78. The main problem remaining to be investigated is how various concentrations of each of the title substances react in the presence of others [synergistic effects] as well as in the presence of other materials such as moisture, carbon monoxide, hydrocarbons and some trace metals. Data must be gathered on how these materials act biologically on humans as well as basic information on the physiological chemistry of lung action. Basic research on human response to these substances in the field of psychological effects is also needed.

1.7 *Determine the effect of major constituents of power plant effluents on vegetation.*

The tendency to build power plants away from urban areas and use of the tall stack means that more plant effluent is reaching rural areas. One of the major areas for research is how our effluents affect vegetation including crops. Studies to date have been sketchy and generally inconclusive.

Further research is necessary in the areas of plant chemistry and physiology in order to pinpoint short- and long-term effects of substances such as oxides of nitrogen and sulfur in combination with common synergists such as hydrocarbons, carbon monoxide and ozone. We must be able to differentiate these effects from effects caused by differences in humidity, light, soil chemistry and natural variation. Studies to date have not been adequate to determine this.

1.8 *Study the synergistic effects of the major stack gas constituents in the atmosphere.*

This goal is aimed at the study of the chemistry and physics of major stack gas constituents in the atmosphere. Just as a carbon-cycle can be depicted so can sulfur and nitrogen cycles. Somewhere in their cycles between birth and decay, these compounds interact with other constituents of the atmosphere to produce effects such as smog, acid rains, declining pH of surface waters and gray and brown cities.

Investigation into these ecological cycles is necessary. Information needed includes data on nitrogen and sulfur sinks and the ecological half-life of the oxide forms of sulfur and nitrogen as well as the build-up rates of the slow reaction rate product in the cycles.

Other information that is necessary includes knowledge of particle-gas reactions and gas-gas reactions with a solid product as they occur in our atmosphere.

1.9 *Develop standardized portable measuring instruments for the measurement of low concentrations of oxides of nitrogen and sulfur and particulates.*

Central to the whole issue of air quality is the ability to measure and correlate what we can determine in the way of concentrations of the emitted contaminants with effects that we can see. Analytical instrumentation in use for measuring these contaminants is bulky, complex and liable to interferences. Further, maintenance is high and very skilled personnel are needed to obtain information that is consistent, reproducible and correlatable between laboratory tests. As we begin to remove the oxides and concentrations begin to decline, today's instrumentation simply will not be sensitive enough for monitoring purposes. Areas of interest that should be investigated are gas chromatography, ultraviolet and infrared emission and absorption techniques, as well as color spot test tubes and chemical reactions that could be used to integrate values over long periods of time.

1.10 *Determine the distribution and effects of minor constituents of stack emissions.*

Mercury in coal has led to an intense interest in the determination of minor elements in stack gases. Included are the determination of concentrations and forms, determination of geochemical fate, and the biological half-life of these materials. Laboratory studies are necessary to determine the effects of these constituents on plants and animals. One such element already under scrutiny, although not from power plants, is lead from automotive exhausts. The fulfillment of this goal would enable us to understand and be able to predict and anticipate environmental changes that might be caused by these minor or trace constituents.

It is a documented fact that in many cases elements which are toxic in higher concentrations have been found to be necessary in biochemical systems at trace levels. For example, Al, B, Mn, Zn, Cu, Mo and Co in small amounts are necessary for proper plant growth. This type of knowledge is important and could fill a valuable void in the present day knowledge of biochemistry.

1.11 *Improve dispersion technology.*

This goal is aimed at supplying knowledge that must be available if our industry is to make the best use of alternate methods of cooling for condenser discharges. As such, this supporting goal in part is an intermediate one between air quality and water quality considerations. We must determine how plumes from evaporative cooling systems interact with normal constituents of stack gases and determine whether techniques can be developed for penetration of inversions. Another area for consideration is the further advancement of our ideas in the field of correlation of multiple source emission and ground level concentration of stack gas constituents.

1.12 *Study effects of alternate cooling systems.*

The need to develop alternate methods of cooling that are compatible with the environment for old and new plants leads to the necessity for the development of methods to predict and simulate their effects on the environment. These investigations will include studies on dry and wet towers and spray ponds with basic climatological studies and field measurements to check model and analytical predictions.

This supporting goal, the last of the air quality group, has been restricted to atmospheric effects of these alternate cooling methods, leaving, arbitrarily, the development of hardware and advanced technology for a supporting goal in the water quality area [see supporting goal 2.3].

WATER QUALITY

There are advanced generating cycles such as the Brayton cycle available in which water is not used for cooling; however, these are more properly covered in the energy conversion area. Other advanced conversion methods have also been left to the energy conversion area. Since cooling water problems affect nuclear plants, perhaps more than corresponding fossil plants, and since no radiation effects will be considered under water quality, fossil and nuclear discharge will be lumped under one heading. Finally, although it appears that cooling water problems are more regional in character than air quality problems, these considerations have not been identified as regional even though input has been obtained from all regions of the country.

2.1 *Investigate effects arising from disposal of solid and liquid wastes from power plant operations.*

In the broad area of environmental quality, in many cases, inherent in the solution of one type of problem, is the creation of a problem in another environmental area. For example, if we remove more particulates from stack gas, we have more waste of which to dispose; in using cooling towers to prevent thermal effects, we might cause atmospheric effects and so on.

In the area of removal of oxides of nitrogen and sulfur via throw-away systems, we create a waste product with a potential for affecting water quality. It behooves us to investigate this potential problem before the fact and, if possible, turn this waste product to a beneficial use. First, we must pinpoint those products that could prove troublesome and develop quantitative data relating to types and quantities of runoff and seepage from disposal areas. We must be able to predict what effect runoff and seepage will have on water supplies. Finally, should it appear that harmful effects could arise from disposal areas, we must find methods of fixing contaminants into the solid waste. Another major area for investigation is the possible uses for solid wastes from removal processes.

2.2 *Determine the effects of once-through cooling systems on aquatic biota.*

The question of the effect of heated water discharges currently is receiving much attention. While it is obvious that "too much" heat can be deleterious to aquatic life, just where the "too much" point occurs is extremely unclear. In many cases, heated water discharges are beneficial. A combination of realistic laboratory and actual field research is necessary.

Investigation into the biological effects of heated water discharges involves studying the chemistry and physics of bodies of water as well as the biology. It encompasses not only effects of the heated water on the receiving body but also the effects of entrainment upon aquatic organisms. This research must take into account all aspects of the food web. Since types of organisms involved are geography dependent, a regional approach must be taken to these problems. Ideally, this research would lead to a number of predictive regional models that could be used to assess changes that could occur because of an increased heat load on a receiving stream. Under this supporting goal is the study of intake structure design leading to means of minimizing entrainment of fish. Finally included is basic research into computer modeling of heat transfer between water and air and water and heated water in fresh water situations, sea water situations, and under estuarine conditions.

2.3 *Develop viable alternate methods of cooling heated water discharges.*

Alternate cooling methods have been available to utilities for decades but not in the sizes required for modern large units. There is a need to be ready with alternates should they become necessary on either a retrofit or new basis and in some situations, viable, optimized alternate cooling methods may be the economic choice and so should be available.

This supporting goal contains the main hardware development portion of the water quality area. It involves research directed towards advanced cooling tower design including fundamental research into heat transfer between water and air and optimum design for wet cooling towers. Basic investigation into properties and types of heat transfer surfaces for dry towers will be performed. Another area in which research will also be performed is on the concept of a topping cycle utilizing spray nozzles. Basic theoretical understanding of the processes involved in these areas should lead to less costly and more efficient methods of alternate cooling.

2.4 *Participate in a study to evaluate the effects of heated water discharges on the health and aging of aquatic ecosystems.*

This supporting goal is not so much an evaluation of effects of heated water [covered under 2.2] as it is an effort to determine the state of health of a portion of our environment in order to determine whether local water supplies can be used for once-through cooling purposes. Because of the potential immensity of this field of endeavor, it was felt that the utilities should undertake only a portion of the entire study. The investigation would cover successional patterns of flora and fauna, fish population dynamics, and energy transfer between various portions of the environment such as forests, grasslands, streams, and lakes including nutrient cycles. Such a study could easily consume a considerable body of personnel for a lifetime. It involves not only water quality but air quality and radiological effects as well. As such, it relates more directly to plant siting. However, it seems that utility interest is more properly involved in the water quality portion and, as such, the supporting goal falls into the water quality area.

NUCLEAR

Having progressed to this point, one may well be disappointed because of the paucity of nuclear-related environmental research and development supporting goals for the industry. Two points must be remembered which pertain to both fossil and nuclear plants:

[1] Many problem areas have already been covered in the air and water quality sections of this report; e.g., alternate cooling, meterology of cooling towers, heated cooling water effects, etc.

[2] The AEC has, generally speaking, carried on extensive programs of research through the National Laboratories on radiation and its effects and has caused, through plant licensing procedures, ever increasingly thorough investigations of environmental factors over that which has been the practice for fossil plants.

It should also be remembered that programs such as development of breeder reactors, higher temperature fuel development, and others which would tend to lessen the environmental impact of a nuclear plant are being handled in the energy conversion section of this report.

The same situation applies to nuclear fuel reprocessing wastes. In general, these wastes must be stored safely for 600-1000 years. The AEC has performed extensive research on processing these wastes via their incorporation in non-leachable glassy solids. At this time, it appears that this is an acceptable method. In the future, it may become necessary to participate in the funding as deemed appropriate at that particular time.

3.1 *Further reduce radiation release from the overall nuclear cycle.*

Present AEC regulations reflect an increasing pressure to reduce the radioactive content of nuclear plant effluents to the lowest practicable level. To accomplish this, methods for the removal and safe long-term storage of Kr-85 must be developed; charcoal filter systems, used in the removal of radioactive elemental iodines and organic iodides must be perfected; and methods for the continuous sampling and removal of tritium from gaseous and aqueous wastes must be studied.

Present instruments cannot continuously

measure radiation and/or concentrations of radioactive materials at less than background levels. Such monitoring equipment will be required and the necessary research and development must be undertaken soon.

The efficiency of radioactive waste treatment systems may require improvement to meet current, more restrictive regulatory limits, and development work to improve the efficiency of components such as evaporators and demineralizers is required.

As nuclear plants age and are decommissioned, techniques for accomplishing this in a safe and economical manner must be developed. As a starting point, an evaluation of the decommissioning operations of the past 15 to 20 years must be made.

3.2 *Determine cumulative effects of small amounts of radioisotopes on biological systems.*

Nuclear power plants are currently being designed such that the dose to the public resulting from the operation of such plants should not exceed a small fraction of the dose due to natural background radiation and radioactivity. A considerable body of data exists concerning the effect on biological systems of continuous low-level radiation and/or the continuous intake of low concentrations of radionuclides, and more data will become available as long-term studies, some over 20 years in duration, are concluded. Such studies and the data produced by them must be evaluated and utilized in assessing the effect of reactor-induced doses on bio-systems, especially man. Methods of data presentation in a form with maximum public credibility must be developed.

On-going studies should be evaluated and where important research may be curtailed or ceased, due to cutbacks in government research and development funding, some method of assistance should be developed.

A most important area, where additional research programs are required, is the determination of the fate of radionuclides introduced into the terrestrial and aquatic food webs, especially those leading to man.

GENERAL

This section contains supporting goals which could not easily be placed into other categories. In general, these goals tend to be long-term in nature. They constitute the types of programs in which the utility industry would play a participatory role rather than undertake the cost of the entire project.

4.1 *Determine the health effects of exposure in electromagnetic fields.*

Although we have been transferring huge quantities of electric energy from place to place for generations, more research is needed on chronic effects of long exposures to electromagnetic radiation. Similarly, more research is needed relative to health effects related to multiple short exposures to high-intensity fields, including psychological and behavioral effects. This supporting goal is in essence a low-priority, long-term investigation of low-level biological effects that might be expected to show up only after years or generations of exposure. This project involves the determination of what could be a very small effect in relation to a relatively high natural background.

4.2 *Develop regional siting criteria for fossil fuel and nuclear power plants.*

Past siting practices in the utility field have taken cognizance of environmental matters. Today, and in the future, however, closer scrutiny of environmental factors will undoubtedly lead to a drastic reduction in the number of new sites that are acceptable to various levels of government and the public. In particular, the various parameters involved in siting such as cooling water supplies, closeness to supplies of fuel and use centers, aesthetics, site type, meterological conditions, etc., should be utilized in the development of a computer model to predict optimum balance of the various factors to ensure minimum environmental intrusion for a given site. Part of such a program is under development under the auspices of EEI RP-49. Work on the model should be continued and expanded to include offshore and underground siting practices as well.

4.3 *Develop methods of noise control and noise specifications for power plant equipment.*

An environmental factor coming into increased prominence in today's thinking is noise. This supporting goal is designed to study and develop methods for noise control in existing and future plants. Examples of types of equipment that must be quieted include pumps, fans, motors, and coal mills. Also needed are criteria for acoustic room design of power plants to get away from the reverberent quality of present plants. Further, in conjunction with manufacturers, noise specifications for new power plant equipment must be developed so as to include octave band sound power levels and sound pressure levels. Finally, noise specifications and criteria must be developed for outdoor equipment so as to have a minimal effect on the surrounding community.

4.4 *Develop ecosystem and climatological models to predict long-term effects caused by power generation.*

"Is man detrimentally modifying, on a long-term basis, his environment?" is a difficult question to answer. This supporting goal is aimed at answering the portion of the question as it relates to power generation. Investigations should include research into carbon dioxide sources and sinks, effects of moisture, the greenhouse effect as modified by particulates, and development of meterological models which would allow predictive determination of the effects of power generation on our environment.

Appendix D – Part I describes in more detail the specific tasks that must be performed to accomplish these goals. Their priority and costs are also listed.

CHAPTER 5

ENERGY UTILIZATION

Probably all specific R&D goals in the other chapters of this report relate, directly or indirectly, to one ultimate goal: to enable our citizens to use all the electric energy they need for a better life and better environment.

The Task Force recognizes that the success of this ultimate goal will depend heavily on the success our industry has in meeting its other goals – to make electrical operations environmentally acceptable, to make the supply adequate, reliable and economic, and to minimize the drain on natural resources.

The basic thrust of the utilization R&D goals program is one of intensifying R&D in selected areas such as improving the efficiency of utilization devices and developing optimal substitution in the nation's total energy requirements with electrical energy where it will produce a net environmental improvement.

SPECIFIC GOALS

The specific goals of this Task Force in the area of energy utilization are as follows:

1. To increase the efficiency of consumer devices in home and commerce, thus reducing the consumption of energy per unit of light, heat or cooling, and contributing to wise use and conservation of energy.
2. To develop concepts and equipment (batteries foremost) to make possible widespread use of electric energy to power mass transportation, personal and specialty transportation, thereby reducing air pollution.
3. To develop beneficial uses – such as space heating, aquaculture and agricultural applications – for the presently non-usable low grade heat now rejected in the production of electricity, and thus reduce thermal problems.
4. To develop high efficiency air pollution controls for industries other than the electric industry, including more efficient filters, scrubbers, collectors, electrostatic and ultrasonic precipitators. (Air pollution controls for the electric industry are goals of other chapters.)
5. To improve and develop new equipment to clean up our rivers and lakes and to improve treatment of sewage and solid waste.

6. To study, test and develop possible further application of electric energy to improve manufacturing technology, improve product, increase productivity, reduce pollution and conserve fossil fuels.
7. To study and develop new methods of food production, processing, storage, preservation, and distribution that utilize electricity, thus reducing man's dependence on weather and improving his diet.
8. To improve communications technology, including gathering, processing, transmitting, and utilization of information.
9. To improve and develop new equipment to reduce noise from operation of electro-mechanical equipment of all kinds.
10. To improve and develop new electric residential task saving and leisure time equipment.

These goals relate to customer-owned equipment and, obviously, manufacturers are working on many aspects of this research and development. We propose to concentrate on areas where the benefits to our industry are as great or greater than to manufacturers, and where there seem to be the greatest potential benefits to customers and the environment.

PRIORITIES AND COSTS

The above goals involve many specific projects falling into six basic categories of opportunity: (1) environment, (2) transportation, (3) agriculture, (4) manufacturing, (5) efficient use of energy in home and commerce, and (6) communications. Figure 5 shows the distribution of estimated costs for energy utilization R&D. Table V shows the priorities and costs.

Following is a general discussion and justification of the goals of this chapter, divided into the six broad categories of opportunity. Appendix E further defines the six basic categories into 13 distinct opportunity areas.

ENVIRONMENT

We doubt many would quarrel with our emphasis on the use of electricity for the improvement of the environment. The very existence of man and his activities depend upon the environment. Never before has man focused his attention upon his surroundings as he now does. The focus will become even sharper as environmental issues become more and more vital to mankind and his planet. It follows that in a milieu of social, political, and industrial pressures, environment may become our most important priority of the future.

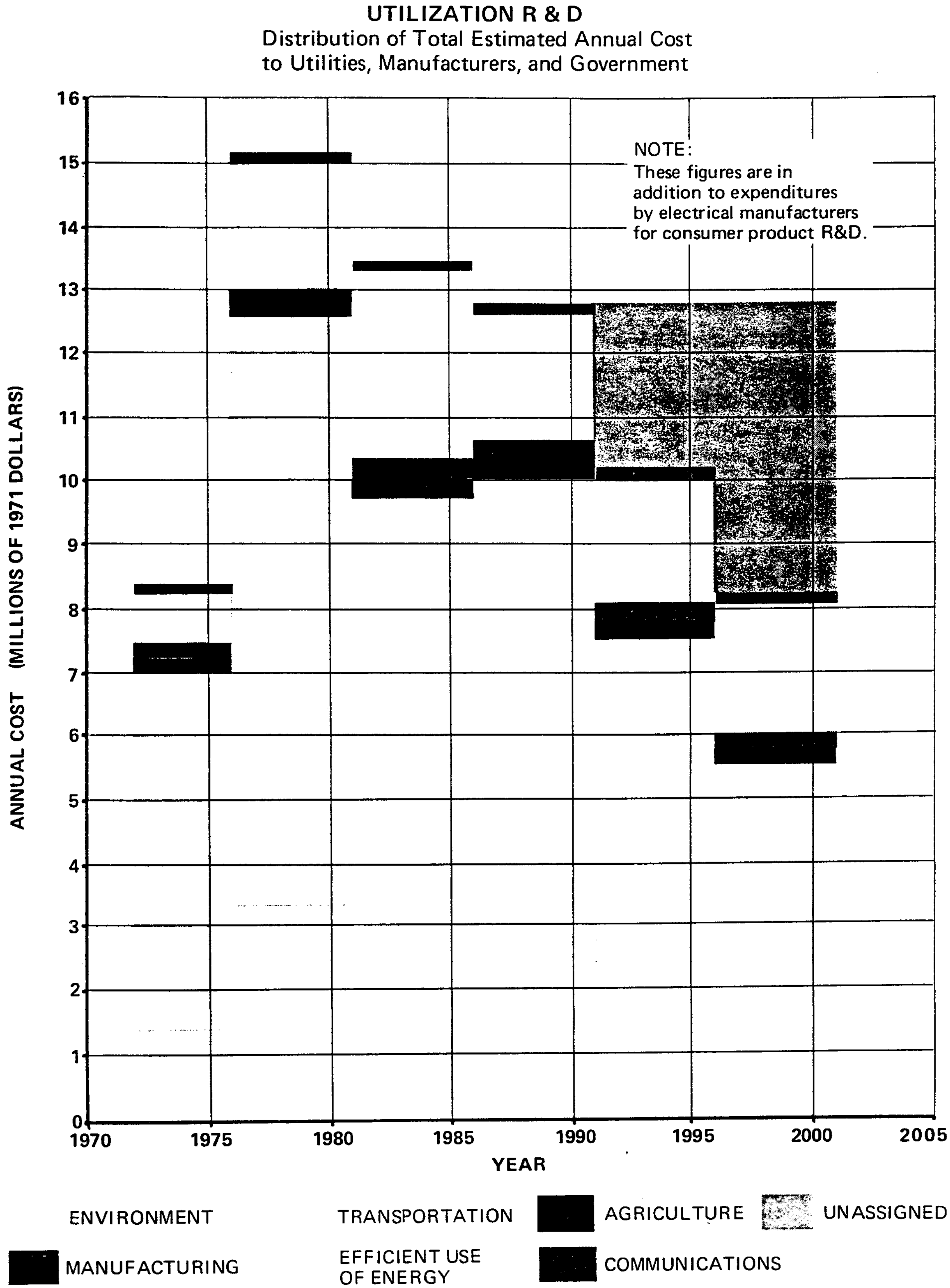
For our purposes, the environmental area of opportunity falls mainly into two important classifications: natural environment and social environment. In turn, each of these two classifications may be further defined into its own pertinent classifications, and each of these – as with the major categories – has its own history, status, needs, benefits, costs, problems, and future.

Natural Environment

Utilization of electric energy in relation to natural environment opens a broad field for research and development. Not only may electric energy lead to greatly improved utilization of resources, but it can contribute significantly to conservation and improvement of the ecology. Representative projects to which the efforts of this task force may be directed in this area include:

1. Waste heat utilization
2. Air pollution controls
3. Water and sewage treatment
   a. urban water processing
   b. river and lakes clean-up
   c. solid waste management

It is of utmost importance that industry demonstrate leadership in maintaining a harmonious relationship on environmental concerns. This program projects study,



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to the Electric Research Council,
June, 1971

FIGURE 5

TABLE V

UTILIZATION R&D

SUMMARY OF COSTS TO UTILITIES, MANUFACTURERS, AND GOVERNMENT

(Millions of 1971 Dollars)

Priority	Project	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 1995	1996 2000	TOTALS
1	Environment: 1) Waste heat utilization 2) Air pollution controls 3) Water and sewage treatment	1.2	1.2	1.2	1.2	3.0	3.0	3.0	3.0	3.0	15.0	12.5	10.0	10.0	67.3
	Transportation: 1) Materials 2) Mass 3) Personal	5.5	5.5	5.5	5.5	9.2	9.2	9.2	9.2	9.2	31.0	36.0	26.0	16.0	177.0
	Manufacturing: Systems to 1) Replace polluting systems 2) Increase productivity	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.5	1.5	1.5	1.5	7.8
	Efficient Use of Energy in Home and Commerce: 1) Structural systems and components 2) Systems and Appliances 3) Lighting systems 4) Environmental systems	1.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	2.0	15.0	10.0	10.0	10.0	59.0
	Subtotals	**7.9**	**7.9**	**7.9**	**7.9**	**14.4**	**14.4**	**14.4**	**14.4**	**14.4**	**62.5**	**60.0**	**47.5**	**37.5**	**311.1**
2	Environment: Standard of Living	0.03	0.03	0.03	0.03	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	1.8
3	Environment: Noise Control	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	1.0	–	–	–	2.4
	Agriculture: 1) Production 2) Processing 3) Storage	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.5	1.5	1.5	1.5	7.8
	Communications: 1) Business and Personal 2) Education	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	1.0	1.0	1.0	1.0	5.4
	Subtotals	**0.4**	**0.4**	**0.4**	**0.4**	**0.6**	**0.6**	**0.6**	**0.6**	**0.6**	**3.5**	**2.5**	**2.5**	**2.5**	**15.6**
4	Environment: Leisure Time	0.03	0.03	0.03	0.03	0.1	0.1	0.1	0.1	0.1	1.0	1.0	1.0	1.0	4.6
	TOTALS	**8.4**	**8.4**	**8.4**	**8.4**	**15.2**	**15.2**	**15.2**	**15.2**	**15.2**	**67.3**	**63.8**	**51.3**	**41.3**	**333**
	Unassigned												13	23	36
	Totals Including Unassigned	**8.4**	**8.4**	**8.4**	**8.4**	**15.2**	**15.2**	**15.2**	**15.2**	**15.2**	**67.3**	**63.8**	**64**	**64**	**369**

Note: These utilization figures are in addition to expenditures by electrical manufacturers for consumer product R&D.

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laboratory development and demonstration. A specific project will be to demonstrate physically by a pilot plant study an integrated system for food production and waste disposal utilizing waste heat from thermoelectric power plants by 1975.

Social Environment

The utilization of electric energy in the future social environment is closely allied to constantly shifting socio-economic trends in the world, and to the needs and demands of a new world of new generations reared in the most scientifically sophisticated age we have ever known. The members of these generations probably will work fewer hours, find new ways to occupy their time, and increasingly will expect the fruits of science and technology to serve them and their way of life.

Three representative fields for research and development in social environment indicate the direction in which these efforts may proceed:

1. Standard of living
2. Noise control
3. Leisure time

Social environment is largely concerned with the way people live, how they use their time, and what they want and need for personal convenience and day-to-day living. Working conditions become a part of social environment, as do homes, facilities for entertainment or recreation, or medical centers. Problems inherent with meeting the onrushing needs of a rapidly changing living mode may be centered around the ability to keep abreast of the demands. Also because of changing attitudes among younger generations toward life styles, ecology, consumerism, government, and industry, our research and development should be especially alert to trends that will affect electric energy utilization.

This program addresses itself to the important opportunity to identify, test, and correlate socio-economic trends to energy usage. Significant input on the correlation of standards of living by energy usage is envisioned by 1975.

TRANSPORTATION

Transportation offers a major area for electrical energy research and development. A well-balanced transportation system, developed with judicious planning of land use, can improve the quality of urban life by optimizing the mobility of people and goods, reducing air and noise pollution, increasing real estate values, and minimizing the imprudent use of valuable property for expressways, parking lots and streets. Acceptance by the public, with consequent realization of these benefits, will depend on how well public and private systems are designed to complement each other; that is, if electrified public transportation can be made comfortable, clean, quiet, safe, fast, dependable and convenient; and if private vehicles can be electrified and their use incorporated efficiently into the overall ground transportation system. It is the goal of this area of research to develop concepts and equipment that will achieve such acceptance.

A primary objective will be the development of higher energy - density transportable power sources. Specifically this program envisions the doubling of the energy - density capability of the existing battery systems by 1975; 80-100 Wh/pound systems by 1980; and 150-200 Wh/pound systems by 1990.

Transportation may be divided roughly into three fields: materials transportation and special service vehicles; mass transportation; and personal transportation. They fall somewhat in that order of priority. Each field may be divided into specific projects.

Materials Transportation and Special Service Vehicles

These vehicles include in-plant vehicles such as fork lift, pallet, reach, and platform trucks, food service carts, tractors, personnel carriers. A related category, special service vehicles, may include delivery vans, fire engines, ambulances, shopping and baggage carts, personnel carriers, and other specialized in-street vehicles.

It is estimated that 750,000 in-plant vehicles are used in this nation. The need is constant and growing. Electric vehicles usually are competitive in price with others, last longer, cost less to maintain and operate, are quiet, easy and safe to use, efficient and cause no air pollution.

On-going research into equipment improvement is essential. This includes battery research and development. In the United States, only about one-third of the in-plant vehicles are electric. In the United Kingdom, two-thirds are electrically powered. It is estimated that within a short time this market could absorb about 50,000 new in-plant electric units each year.

Mass Transportation

We are concerned with two major areas of mass transportation: rapid transit and electrification of railroads.

Urban traffic conditions strangle cities and become steadily less bearable. An apparent need is a balanced system of mass transportation in which rail and highway traffic supplement each other. Buses, automobiles, and freeways form one component of the balance. Rapid transit that can transport large numbers of persons through urban cores on rights-of-way constitute the other component. About forty major United States metropolitan areas could use such systems. Electric transportation meets all rapid transit requirements.

The United States lags in urban balanced systems of mass transportation. Contrasted with many foreign systems, only five exist in this nation. Few are under construction. Some are being planned. But recent progress is encouraging: Philadelphia and South Jersey, Boston, Cleveland, and San Francisco's high-speed, computer-controlled BART system.

Our electrified railroad status is dismal. We have 34% of the world's track miles and less than 4% of the world's electrified track miles. Russia, Japan, Italy, France, and Sweden far surpass us. However, our New York-Washington metroliners in their first year, using millions of kilowatthours, exceeded airline occupancy rates between those two cities.

Electrification of United States railroads would bring obvious advantages to railroads and the public. Modern electric locomotives have longer life, need less maintenance, and can pull heavier loads up steeper grades at faster speeds than diesel engines.

Problems arising from building, expanding, and adapting electric energy to mass transportation become manifold and serious as we examine them. Financing is a major problem, both for building rapid transit systems and converting railroads to electricity.

We must develop a meaningful relationship among land planning, land use and modes of transportation.

Personal Transportation

Included in this classification are leisure time and useful vehicles for home or farm, and the much-discussed electric family car.

There is increasing demand for "fun" vehicles, such as golf carts, scooters, dune buggies, snowmobiles, and other recreation vehicles. With them may be considered farm and home vehicles and equipment such as tractors, mowers, snow movers, tillers, haulers. Not only do these uses merit close R&D attention in themselves, but they may help pave the way toward the electric family car.

The task of personal transportation may well be defined into two areas: short range, moderate speed, two to four passenger; and long-range, freeway speed, five to six passenger. Improved battery systems or another high energy-density power source must be developed.

This improved transportable electric power source coupled with systems analysis of the task to be performed will afford a new opportunity in personal transportation. Market Research indicates that 50 million Americans might buy a short-range, limited speed electric car priced at $2,000. That may define the challenge and the thrust of research and development in this area of utilization.

AGRICULTURE

Over the past few decades, the field of agriculture has been altered in nearly every way. Not only has the ownership pattern varied from the small family farm to the larger business or corporate enterprise, but the changes in the technology, distribution, employment, and processing and growing of the products have been revolutionary.

We have seen the electrification of nearly every farm, no matter how remote, in the past few decades. True, that per acre yields have been increased to levels considered impossible only a few years ago. True, that processing methods have made it possible to receive and handle larger amounts of produce in a shorter period of time than ever before; and, it is factual that storage methods have made it possible to retain the finished item in good condition longer than ever before. But what can be done from here?

Electricity has played the greatest role in these changes which have altered the farm from an artistic to a scientific operation. There are many opportunities for further expansion in per acre yields by using waste heat, for lighting methods which will increase growing seasons, even for expansions in the output of animal and poultry production through climate controls in their maturing environments.

Through the greater and greater uses of electricity not only will fewer people succeed in producing an abundance of edible products resulting in a more pleasant life for the farmer, but, in doing so, a more complete diet for the peoples of the world will be provided. The opportunities are endless, even to the use of land which may now be marginally productive. Through improved and more productive agriculture, the world is the benefactor.

Research is important not only into more productive genetic types of seeds, but the effect of improved environmental effects upon them. Is it not possible that electricity, through research, can reduce the farmer's dependence upon his friend and enemy – the weather?

MANUFACTURING

Where would we be today if the wheels of manufacturing were turned only by a brace of fine oxen or a donkey circling a fixed post? Where would industry be if horsepower were really horsepower complete with four legs and a tail? The industrial revolution has indeed prospered under the ever greater inputs of electricity and will no doubt find electricity the catalyst to yet greater production. The secret to the standard of living improvement has been that, through more sophisticated production methods, fewer people have been able to bring abundance to more.

While we can point with pride at the accomplishments of research in electrifying the factory and thus making it vastly safer, healthier, more productive; nonetheless, we can look at the great opportunities that lie ahead. In this enlightened era, have we fully investigated the improvement in climate control and improved lighting where we must have human workers?

We must investigate those areas where automation can be applied where none exists at the moment. We must investigate opportunities for improvement in performance from those automated applications which now exist. All of this means a substitution of kilowatthours for human time with the resultant improvement of the standard of living of those around us.

As we in America improve our productive methods, we not only improve our own citizen's life, but the life of all those in the world. What we produce in abundance at a price attractive to those in the world becomes a factor in the continued strength of the national economy.

All of us are well aware of the traditional concept of a factory. It belches out vast quantities of heavy black smoke or produces an odor which ruins meals for miles around. Electricity can solve both problems, and will be doing so in greater quantity in the years ahead. Perhaps the day when absolutely no emission comes forth from a plant is a few years away, but electricity can both make that day sooner and make the time until then far less unpleasant.

EFFICIENT USE OF ENERGY IN HOME AND COMMERCE

It is of utmost importance that industry improve its application of energy in home and commerce. This program envisions the near-term improvement in the efficiency of heating, cooling, lighting and ventilating sources and devices. Specific projects for immediate implementation include: improvement of reliability and efficiency of the heat pump; improve efficiency of electric air conditioning; longer life and more efficient lighting equipment; and energy conservation techniques in construction.

One of the more fertile areas for development is the area of new appliances for home and commerce. Realizing that even air conditioning was rare in many sections of the country except in theaters until the past few decades, no one today would build an office building without some type of climate control, but what can be yet developed to make the occupants of a building more productive?

Improvements in lighting and climate control are on the horizon. We need to make it possible for those who live and work anywhere in the country to enjoy the same environmental benefits as those living anywhere else. With covered malls, we have made shopping a pleasure in January in even the coldest parts of the country.

Over the past decades, the increased use of electricity in the construction trades has not been as apparent as in other fields. To the average observer, the nails are still pounded by hand and the materials still seem to be moved by the strong back of a workman. But a revolution in building and the functions within is occurring, and we have just begun to see some of the fringe differences.

On-site building has been the norm ever since the beginning of time; but we are finding that through the use of modern factory methods, greater value can be given to the ultimate owner of the building than is possible by on-site methods. Certainly, this improves the living standard for Americans.

COMMUNICATIONS

It has been said that, of all the arts, communication has been by far the most rapidly growing. We are bombarded on all sides by visual, aural, and sensory communications. Some learned psychiatrists have indicated that the human body might soon be reaching the saturation point in communications – it can take no more. Whether this is true or not is a matter of conjecture, but the rise has been great from the time that the cave man found the sounds of birds, animals, the wind and the sea, plus other humans, his only contact aurally with the world.

If we, as individuals, have reached the limit of our ability to absorb additional messages, certainly there is no foreseeable limit in the amount of data that we are gathering and can store. Business, and individuals also, have found it necessary to have additional facts at their disposal in order to make more intelligent decisions. The collection of data, thus, has been a growing and necessary part of the operation of all business and personal activities.

Opportunities for the electrical industry exist not only in the improvement of data transmission but in the extent to which it is transmitted and the actions which result from having such information.

Research is necessary to develop methods of applying more intelligent information directly to a task. Research is also necessary to identify the physiological, sociological, and economic relationships with customers as they become more dependent upon electrical energy.

Appendix E further refines the six basic categories into 13 distinct opportunity areas.

CHAPTER 6

INDUSTRY GROWTH AND SYSTEM DEVELOPMENT

To accomplish our goals of adequate, reliable and economical electrical energy through socially and environmentally acceptable methods, it is necessary to anticipate the general character of power systems 10, 20 and 30 years hence, and to recommend research studies which will provide industry guidance.

SPECIFIC GOALS

1. Develop and continually update a National Fuel Model in order to gain knowledge of fuels and their availability and thus to help determine the nature and fuel limitations of future energy conversion systems. The National Fuel Model would include determination of: 1] long-range availability of "non-renewable" fossil and nuclear fuels; 2] long-range cost of recovering and transporting these fuels, and 3] long-range requirements of various fuels based on energy conversion cost.
2. Develop and continually update, through use of modeling techniques, the capital and operating cost of transporting energy in the best method of ultimate delivery of energy to the customer and to help determine optimum plant location. This would include: 1] electric power, overhead and underground, ac and dc, at various voltages and frequencies; 2] coal by train, ship or in pipe [with water, oil or other fluid]; 3] oil by train, pipe or ship; 4] gas [natural, synthetic or hydrogen] by pipe, train or ship in gaseous or liquid form, and 5] nuclear fuels such as uranium, thorium, deuterium, lithium in the natural form or refined.
3. Develop an overall power system model from the fuel to the consumer during the next 30 years, in order to gain a balanced view of the economics of the total system as well as the physical shape of the system. This would include: 1] forecast of electric energy requirements; 2] fuels; 3] modes of conversion; 4] energy storage; 5] modes of energy transport; 6] transmission systems; 7] reliability, and 8] costs.

4. Develop overall design concepts and the effect on reliability of distributed generation units and their integration into a power system, in order to reduce siting problems, waste heat dissipation problems and transmission requirements. These would include: 1] fuel cells using natural gas, liquid fuel or hydrogen piped to or stored at the site; 2] MHD, and 3] small rotating generating equipment using fuels listed above.

5. Develop the overall concept and effect on reliability of large generation parks or off-shore installations and their integration into a power system, in order to make most efficient use of sites including use of by-products and spent fuel from the production of electricity. These considerations would include: 1] a group of large fossil, fission or fusion generating units; 2] fuel delivery and processing problems; 3] waste processing provisions; 4] environmental problems, and 5] electric energy transport problems.

6. Study the interrelation between the availability of electric energy and the community as well as its effect on social and financial structures, including: 1] availability of electricity as a factor in social advancement; 2] use of electricity as a function of cost; 3] financing problems of government and investor-owned utilities, and 4] interrelations of government and investor-owned utilities.

7. Provide for physical protection of the power system, including: 1] protection against subversive activity; 2] protection against natural and man-made catastrophies, and 3] methods to minimize damage and duration of a power outage.

8. Study and advance methods for recycling waste and restoring land, including: 1] use of trash and garbage as a fuel; 2] use of sewage as a fuel, and 3] restoring areas used for mining, generation or transmission when they are no longer useful.

9. Continually update studies of population and load characteristics, including: 1] population growth; 2] load growth; 3] load densities, and 4] power utilization.

10. Study and develop methods for direct utilization of dc by consumers, with the aim to eliminate the cost of conversion to ac when direct current is generated by MHD, fuel cells or other dc generators.

PRIORITIES AND COSTS

In Table VI specific studies are listed, together with priorities and estimated costs by years.

GENERAL SYSTEM CONCEPTS

For utilities, the future is a systems problem.[1*] The industry must meet the problem of size, how to develop and apply new technology to meet growing demand and not choke itself with great amounts of obsolete and undersized facilities.

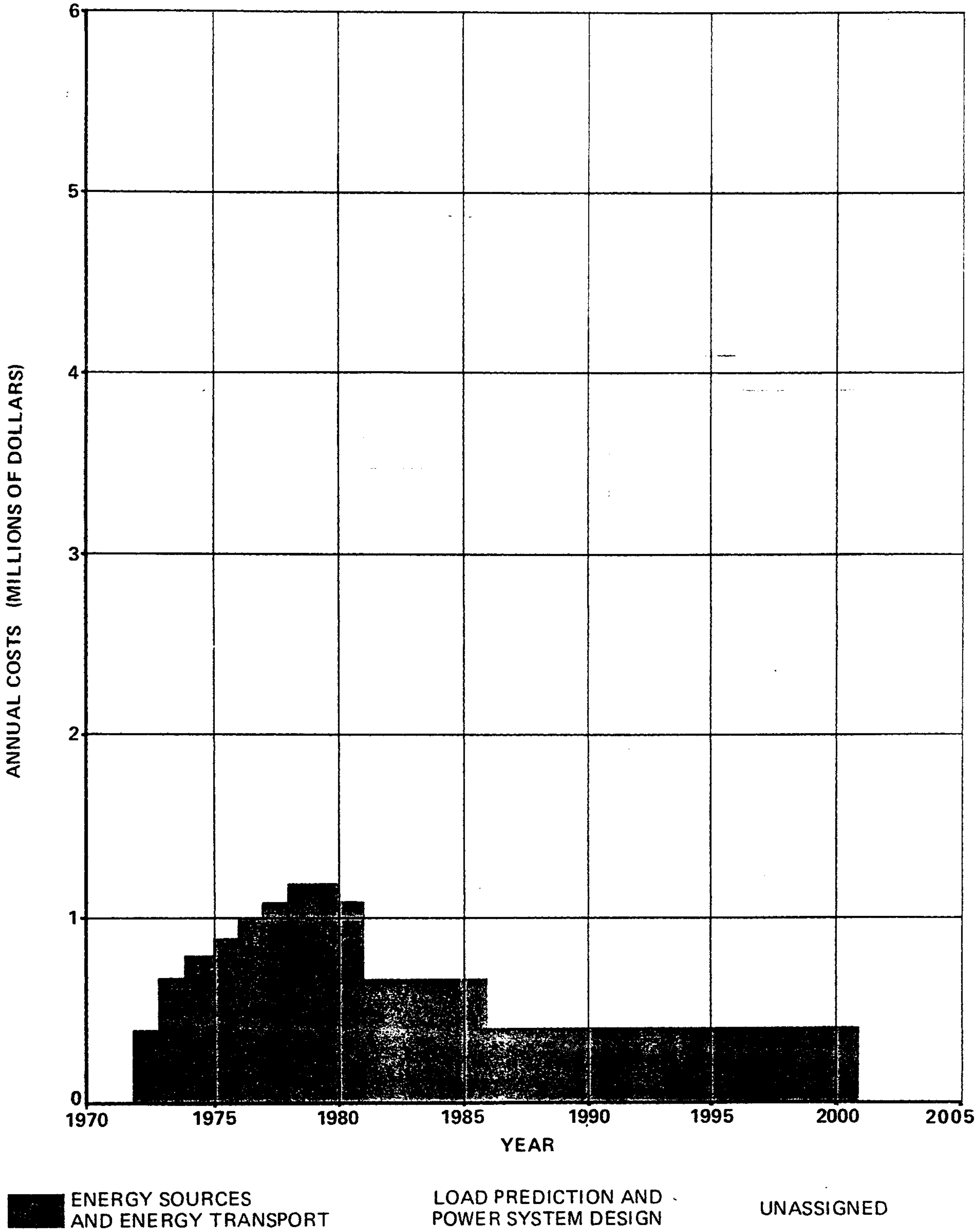
Electrical system features include generation, transmission, distribution and devices for utilization. Forces working to shape the future system are technical, financial, social, and availability of resources. The future systems in different parts of the United States will probably differ as influenced by these factors.

In general terms, space, materials, and sources of energy continue to become more critical. Technology must advance to meet these restrictions. The availability of capital

*see Appendix F – Part IV for references.

GROWTH AND SYSTEMS R & D

Distribution of Total Estimated Annual Cost
to Utilities, Manufacturers, and Government



R & D Goals Task Force Report
to the Electric Research Council,
June, 1971

FIGURE 6

TABLE VI

GROWTH AND SYSTEMS R&D
SUMMARY OF COSTS TO UTILITIES, MANUFACTURERS, AND GOVERNMENT

(Millions of 1971 Dollars)

Priority	Project Description	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 1995	1996 2000	Total
1	Energy Sources National Fuel Model	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	2.1
2	Energy Transport	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	2.1
	Power Systems Design Power System Model	0.5	1.0	1.0	1.0	1.0	0.8	0.8	1.0	1.2	2.2	4.9	7.0	6.3	28.7
	Distributed Generation	0.1	0.1	0.2	0.4	0.4	0.4	0.4	0.4	0.4	1.0	1.0	1.0	1.0	6.8
	Generation Parks	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	1.0	2.0	2.0	7.8
	Social & Financial Structure	0.3	0.9	1.4	1.7	1.9	1.9	1.8	1.7	1.5	6.6	4.4	5.2	4.7	34.0
	Subtotals	**1.2**	**2.3**	**2.9**	**3.4**	**3.6**	**3.4**	**3.3**	**3.4**	**3.4**	**11.1**	**11.6**	**15.5**	**14.3**	**79.4**
3	Power Systems Design Physical Protection	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.6	0.6	2.1	1.5	1.5	1.5	10.5
	Energy Sources- Recycling Waste and Restoring Land	0.2	0.5	0.6	0.7	0.8	0.9	1.0	1.0	0.9	2.9	1.5	1.5	1.5	14.0
	Subtotals	**0.3**	**0.7**	**0.9**	**1.1**	**1.3**	**1.5**	**1.6**	**1.6**	**1.5**	**5.0**	**3.0**	**3.0**	**3.0**	**24.5**
4	Load Prediction Population and Load Characteristics	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	2.1
	Direct Utilization of Direct Current	–	–	–	–	–	–	–	–	0.1	0.7	1.2	1.5	1.5	5.0
	Subtotals	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**1.0**	**1.5**	**1.8**	**1.8**	**7.1**
	Totals	**1.7**	**3.2**	**4.0**	**4.7**	**5.1**	**5.1**	**5.1**	**5.2**	**5.2**	**17.4**	**16.4**	**20.6**	**19.4**	**113.1**
	Unassigned	–	–	–	–	–	–	–	–	–	5.0	5.0	5.0	5.0	20.0
	Totals Including Unassigned	**1.7**	**3.2**	**4.0**	**4.7**	**5.1**	**5.1**	**5.1**	**5.2**	**5.2**	**22.4**	**21.4**	**25.6**	**24.4**	**133**

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at a reasonable annual cost must expand with the increased demand for electric energy, unless other factors, artificial or real, limit the increased demand. The open-ended cycles from electric production, such as waste heat, stack emissions and nuclear byproducts, may have to be closed so that most of the outputs have beneficial uses or are effectively stored. This could mean combining cycles with other types of systems such as desalting water, agricultural and industrial processes and space heating.

GENERATION

Central Station

Central station generation has always meant supply of loads from one or more common power plants. Rotating machines have been scaled up to lower costs and increase efficiency. Financial factors encouraged locating thermal plants close to metropolitan areas and increasing the plant sizes. Hydroelectric plants are usually located remote from loads.

Central stations of the future may be removed from population centers, buried, or even placed under the sea. All chemicals, solids and waste heat must be identified and controlled within criteria established for the specific locations involved. Rational criteria are needed, recognizing that the same level of environmental control is not necessary in all types of sites, and that environment and ecological factors can all be improved through planning.

The maximum acceptable size of generating units, now about 1,000 to 1,300 MW, is being influenced by experience with lowered reliability and the associated need for greater reserves.[2] However, as solutions are found to present equipment problems and power pool loads grow, unit sizes may reach 1,500 MW to 2,500 MW.[3]

The concept of generation parks is receiving attention. These very large complexes would be located outside of urban areas, and would be equipped with the best waste control facilities that it is economic to provide. Where the maximum power plant sizes today are from 2,000 MW to 3,500 MW in systems of 20,000 to 50,000 MW[4] future generation parks of 20,000 to 40,000 MW capacity can be visualized. Since reserves of natural gas and oil are expected to be exhausted before those of coal, more emphasis is expected on generation parks near the coal mines.

Reliability requirements may, however, significantly affect the maximum capability at one site. Failure of a facility common to all units in a plant must not be allowed to shut down the entire plant. Other factors such as local meteorological conditions, water supply, and maximum permissible concentrations of unused chemicals or particle releases may also place limits on maximum size.

Combining the conversion process from fuels to electric energy with other processes to produce closed cycles will become increasingly important. Combined production of synthetic gas, liquid fuel and coke with power generation could be one of these processes. Incineration of garbage is another, and finding uses for the waste heat such as for desalting of water, space heating, and agriculture could substantially increase overall heat utilization efficiency.

The ultimate in combined processes could be the Nuclear Energy Centers Industrial and Agro–Industrial complexes.[5] These centers would include metal reduction and processing, a chemical industry and agricultural processes along with electric power production. At this point, a competitor to electric power transmission may become feasible. This could be production of hydrogen and/or methane for pipeline transport to remote fuel cells.

Distributed Generation

Early forms of distributed generation were essentially the diesel engine generator set and small steam units. Present developments are principally combustion turbines which can be quite compact and can be located on relatively small sites with gas piped to the sites or oil piped or hauled to the sites and stored in tanks. Since these turbines are relatively inefficient, they are used for peaking purposes. However, the new combined cycle gas/steam turbine system promises improved heat rates.

The fuel cell appears to be the most significant future source of distributed generation. Energy could be delivered to fuel cells as pipeline gas or hydrogen gas through pipelines or by truck in a liquid form to local storage containers. In a high density load area the general pattern may be to concentrate fuel cells in community areas of several blocks. Much study is needed to determine the economic size of these fuel cell units.

ENERGY STORAGE SYSTEMS

Pumped storage hydro-stations have been installed on many systems to reduce the need for changing the level of generation of economic central stations and also to make use of excess capacity during off-peak periods. These stations have proved very useful and versatile and now other forms of stored energy appear to be feasible. Energy can be stored in chemical form by using a storage battery with its associated rectifier and inverter system. This may prove very useful since the storage location may be near the load center.

Another means of storing energy is by compressing gas during off-peak hours and then using the gas to drive, or assist in driving, a turbine when electric power is needed.

It is also possible to dissociate water during off-peak hours and store the hydrogen and oxygen so that it may be recombined in a fuel cell or other energy conversion device to generate electricity to meet power system requirements.

Further study is needed to determine the practicability of each of these energy storage methods.

TRANSMISSION SYSTEMS

In the Eastern United States load concentrations around metropolitan areas expanded and fringe area interconnections were established. As service areas combined, transmission lines were built between the points of greatest electrical density, leading to development of larger power plants and local grid systems.

In the Western United States widely separated metropolitan areas developed in association with river basins. Except along the Coast, local grids were small and many were supplied from remote hydroplants over high voltage lines.

Neighboring service areas built high voltage interconnections between respective backbone transmission systems and power pools were formed for joint planning and mutual assistance. As of today, the Eastern United States power system is interconnected and in the Western United States the same process brought about regional interconnection. However, the location and size of existing interconnecting lines are such that area separations occur following some severe disturbances. A set of relatively weak tie-lines exist between the East and West, but could be strengthened for larger energy transfers if economically justified.

Direct-current transmission may become important in conjunction with ac because it is much more efficient for conventional cable circuits, permits rapid control of power flow and does not increase short-circuit currents when connected through converters to large ac buses. For overhead transmission, including terminal equipment, direct current actually becomes cheaper than alternating current, the cost of the two becoming approximately equal in 400 miles or more depending on conditions. Similarly, for conventional underground cable circuits, dc transmission becomes less costly in 20 miles or more. For the future there is a need for lower cost conversion equipment and a dc circuit breaker.

Following are some questions to be answered using system model research.

1. Can high capacity interconnections be justified on the basis of reliability and economic power interchange?

2. What is the relationship among power pool size, unit size, and intertie capacity as these relate to reserve requirements?
3. Can right-of-way problems be solved by combining transmission corridors with highways?
4. Can equitable financial participation in long intertie lines be established for smaller utilities located between large groups?
5. Should dc transmission be used between very large groups to establish frequency independence, control power flow and reduce short circuit duties?

UTILIZATION OF ELECTRICITY

We conclude that 60-Hertz will continue to be the principal frequency for utilization. Other frequencies and dc are expected to be used in relatively limited areas and for special purposes.

Considerable research and development has been done on relatively small ac/dc converter and frequency changing devices. It is anticipated that more uses will be found for conversion equipment, such as to supply 400-Hertz lighting and for chemical processes. The new forces for environmental improvements have stimulated research on the electric automobile and reestablished the importance of heat pumps for space conditioning. Storage batteries could provide an excellent off-peak power system load.

FINANCIAL FACTORS

It has been estimated that utility expenditures on new capital facilities between now and the year 2000 will approach one trillion dollars. Financial processes and legal-financial structures must be studied in order to meet new conditions set by technological, environmental and social factors.

In recent years the lead time between commitment to build large new facilities and on-line date has increased from 5 years to 8, with as long as 10 years likely in the future. Financial procedures must be tailored to this increase and new ideas must be developed to overcome this lost time.

SOCIAL FACTORS

Quality Of Life

An industry goal should be consistently to improve the quality of life. The power industry must identify its contributions to this goal recognizing that it has different meanings to different people and in different places and time.

Where population density is high, electricity is the one energy form offering the greatest comfort using minimum space and with practically no local intrusion on the environment. In assessing priorities, electric space conditioning would be most justified in densely populated areas. More research is needed on the heat pump which transfers heat with a minimum consumptive use of energy.

Security

Provision should be made to guard power systems against subversive activity and against natural and man-made disasters.

ENERGY REQUIREMENTS

Between 1850 and 1970 the poplulation of the United States increased about 9 times and the total energy requirements increased almost 30 times. By the year 2000, it is estimated that a 37 percent growth in population will be accompanied by a 250 percent increase in the use of energy in all forms. This represents a rate of growth in total energy usage about twice that experienced in the past.

The rate of. growth in the use of electric energy for many years has been twice the rate of growth for total energy use. Of the total energy used, 11 percent was converted to electricity in 1920, 20 percent in 1970; and it is estimated that over 30 percent will be converted to electricity by 1980.

Discussions of energy requirements together with estimates of future load characteristics are presented in Part I of Appendix F.

ENERGY SOURCES

The question of energy availability can be simply stated, "How much fuel will be needed, and what fuels will be available?" The specific question that must be answered, however, is, "How much fuel will be available at what cost?" The complexity of this question reflects the complexity of the energy source problem. It is the intent of Part II of Appendix F to provide some clarification of this question and to put it into a research perspective.

ENERGY TRANSPORT

Since the natural sources of energy are rarely, if ever, at the locations where the energy ultimately will be used, it is extremely important to study the comparative costs, as well as other factors which may favor one form of energy transport over another. It will be necessary to study and anticipate the most desirable form of energy transport for any given set of circumstances. Not only must decisions be made as to whether a generating station should be located near the load center or near the source of fuel, but also whether it would be more desirable to have two steps of energy conversion such as from coal to gas and then gas to electricity. A comparison of the cost of transporting energy in various forms of solid, liquid, gaseous, or nuclear fuels is included in Part III of Appendix F.

CHAPTER 7

FUNDAMENTAL RESEARCH

SPECIFIC GOALS

With fundamental research defined as an effort directed toward learning more about the world we live in and how we can interact with it to achieve a better life, we can set forth the following major goals of fundamental research as they relate to the electric utility industry.

1. To learn more about the environmental effects of our activities and how they affect the health and well-being of the populace.
2. To learn more about the physical and chemical processes that take place in our materials and equipment so that we can reduce the cost and further improve the reliability of our electric power supply.
3. To learn more about the basic processes involved in alternative schemes for generating, transmitting, distributing and utilizing electric energy.
4. To learn more about the control and operation of large, expensive and complex systems for the purpose of enhancing the economy and reliability of our service to customers.

INTRODUCTION

In the preceding chapters we have identified the elements of a research and development program that will fill the needs of the utility industry in the future. Considerable care has been taken to set forth a balanced program that gives adequate attention to alternative solutions for power system problems. Although the earlier chapters were organized in terms of applicational needs, with a plea for balance among alternative solutions, implicit in them was balance in another dimension – between research and development. The purpose of this chapter is to expand on this theme by describing in more detail the fundamental research we propose as part of our overall program. Fundamental research is a broad supporting activity underlying the goals of other chapters. The costs of this fundamental research are included in the costs of specific projects in other chapters.

For the purposes of our discussion here we will define fundamental research as effort directed toward learning more about the world we live in and how we can interact with it to achieve a better life. We view fundamental research as spanning the range of activities from basic research whose aim is to increase our store of knowledge for unspecified but expected future use, to applied research which aims to increase our knowledge for the purpose of solving a specific problem. A competent and productive research organization will usually be doing both basic and applied research and it will also generally have professional interactions with development activities.

A good research group, like any other professional group such as an electric utility engineering department, must be built up by carefully selecting people with the right talent, education, and experience and by providing them with the right facilities and environment for productive activity. It takes time to establish a good research group and continuity must be assured for prolonged productivity of the group.

Research and researchers are usually defined in terms of scientific areas rather than in terms of applications. Hence such names as plasma physics, biochemistry, spectroscopy, etc. This tendency leads to groupings of researchers and facilities that are not uniquely coupled to one device or application area. Thus a research group will usually supply research results to several application areas.

The definitions and general properties of research groups and the people that staff them will be illustrated by examples in the following sections. Even though the examples are given to illustrate current needs, their emphasis is not meant to imply any proposed imbalance between basic and applied research. Rather, current needs are all we know about now and we can only guess at future needs in terms of what we know now.

The areas and examples we will cite below are meant to be representative and not exhaustive recitations of all research needs. Most of our fundamental research needs have been stated in the earlier chapters and those citations should be used to establish fundamental research activities as the overall R&D program evolves.

MATERIALS RESEARCH

This is one of the broadest areas in which research needs to be done. Virtually any piece of equipment could be improved if better materials were available.

Because this field is so broad we will discuss different aspects of materials research in terms of the set of physical phenomena being exploited.

Electrical Conduction in Solids

There are three major areas of application that can be enhanced by successful results from fundamental research activities in electrical conduction in solids.

First, and probably most important, are conduction processes that represent imperfections in electrical insulation. They can cause unwanted losses, they can lead to electrical breakdown of the insulation, and they can therefore severely limit the performance of an insulation system. These processes, very much related in detail to those of plasma physics to be discussed later, need to be understood and controlled. Success can lead to thinner ground insulation in turbine generators and hence higher voltage which will reduce cost and increase the efficiency of both the generator and the bus duct that connects it to the unit transformer. Success in this area could also lead to smaller clearances in transformers leading to reduced cost, increased efficiency, and improved reliability. Any other device that depends for its performance on a high-voltage insulation system would also benefit from success in this area.

Another area in which continuing research needs to be done on electrical conduction in solids is in semiconducting materials. Although there are many opportunities for improvements in low-power-level semiconducting devices for control functions and information processing, the greatest benefit will result from semiconductors for circuit breakers, terminals for dc transmission lines, and frequency-changing equipment. In virtually all cases the basic problem is to make a semiconductor that will operate at a higher voltage and be less expensive to manufacture.

The third area is that of good electrical conductors which are needed for transmission and distribution lines and for all electrical equipment. We need to make conductors having lower losses, higher strength, higher operating temperature, and lower cost.

Dielectric Phenomena in Materials

The behavior of dielectric materials generally plays a key role in determining the rating of a piece of equipment. For example, as discussed in the preceding section, the required thickness of ground insulation severely limits the operating voltage of a turbine generator. Similarly, an underground transmission cable has a voltage rating set by the electrical strength of its insulation and a current rating limited in part by the losses in its insulation and by the ability of the insulation to transfer heat to the surrounding medium.

Thus we need to do fundamental research on dielectric behavior of materials to learn more about why dielectrics break down electrically, why they have dielectric losses, and how to control their dielectric constants more effectively. Successful results should lead to more reliable, less expensive equipment.

Magnetic Phenomena in Materials

Research on the magnetic properties of materials is primarily directed toward trying to increase the operating flux density, to decrease the losses, and to make the material less expensive. This is an area in which much work has been done in the past and great strides have been made, especially in the materials used in transformers and rotating machines. Work needs to continue in this area.

Another area for productive research work on magnetic phenomena in materials is in the behavior of ferromagnetic ceramics which are particularly useful in control and communications applications.

It is known that rare earth elements such as Gadolinium and Holmium are ferromagnetic at cryogenic temperatures and have saturation flux densities 3.5 to 5 times as great as the magnetic steels presently used in transformers. If this basic knowledge could be exploited to develop an economic material that would operate at cryogenic temperatures with acceptable losses and have substantially higher saturation flux density than magnetic steel, a tremendous boost would be given to transformers with cryogenic windings and probably to cryogenic underground transmission lines as well.

Strength of Materials

We need to know more about what limits the mechanical strength of a great number of materials for a wide variety of applications. For example, both combustion turbines and steam turbines need turbine blade materials that will operate at higher stress levels and at higher temperatures. The same is true for steam piping. If binary cycles become attractive we will need to know more about materials suitable for handling working fluids other than water in a Rankine cycle.

We need structural materials for power plants, transmission towers, substation structures, and equipment enclosures that are stronger, lighter in weight, and more economical than those materials currently used. We must continue our research on such topics as fatigue and fracture to gain more basic understanding and to point the way for making improvements in materials.

Heat Transfer in Materials

Fundamental research needs to be done on heat transfer in materials with the primary objectives of improved performance and reduced cost.

A dry cooling tower will require a very large amount of heat transfer surface. Applied research needs to be done to determine the most suitable material in terms of material cost, fabrication cost, and acceptable behavior in the environment of a dry cooling tower. A molded plastic, possibly impregnated with material to enhance its heat transfer capability, may be attractive.

One of the largest causes of unreliability in modern, fossil-fired steam-electric plants is the failure of tubes in the steam generator. Research needs to continue to learn more about the processes that lead to these failures. The processes of erosion by entrained particulates in the combustion gases and corrosion by impurities in the condensate and by constituents of the combustion gases need continuing study both in terms of how to make present steam-generator tubes last longer and of how to make better tube materials economically.

Radiation Effects in Materials

Fundamental research needs to continue on how radiation of different types affects the mechanical, thermal, chemical, electric, and magnetic properties of materials. Not only is this knowledge needed for fission reactors to improve on fuel element performance, coolant loop piping, etc., but much basic knowledge will be needed when breeder and fusion reactors are fabricated.

BIOLOGICAL RESEARCH

Fundamental research in biology needs to be done for three major purposes. First, and most important, we need to make certain that all aspects of our activities cause no unacceptable biological effects. The second purpose is to be able to answer with facts any unfounded charges. Third, we need to seek ways of enhancing our biosphere by our operations. The chapter on environment discusses research needs relative to biological effects of power plant emissions, electromagnetic fields and thermal discharges.

PLASMA PHYSICS

Plasma physics, which is commonly accepted as the body of knowledge concerning the behavior of ionized gases, occurs repeatedly in many aspects of electric power system technology. The phenomena are complex and not often understood well enough; consequently, fundamental research in a number of areas of plasma physics will be worthwhile.

The application of plasma physics which probably has the greatest and most far-reaching consequences for electric power is in the fusion reaction. More basic research needs to be done to learn how to contain and heat a plasma to fusion conditions. Even after the scientific feasibility of a fusion reaction has been proven, further plasma physics research will be required to optimize the processes and to provide the information necessary for engineers to fit the fusion reaction into an operating power plant.

Another important area in which plasma physics is applied is in circuit interruption. No matter what kind of circuit breaker, be it oil, SF_6, air blast, magnetic, or vacuum, when the contacts part, current continues to be carried between them by an ionized gas or plasma. To make a breaker operate properly under all conditions, the plasma between the contacts must change from being a good conductor to being a good insulator in a very short time. To engineer such a system requires a knowledge of electrical conduction phenomena, heat transfer, ionization and recombination, and other properties of the plasma. More basic knowledge is needed on the behavior of plasmas under the variety of conditions found in the several types of circuit breakers and thus research should be continued.

The flashover of a transmission line by lightning, switching surges, or contamination failure involves the formation of a plasma. Fundamental research on how these plasmas form is needed to do a better engineering job in avoiding these flashovers.

The breakdown of insulation in transformers, generator stator bars, underground transmission cable, and other apparatus insulated by solids and liquids is generally understood to occur due to small discharges in voids or around impurities. These discharges, which are in ionized gases, grow until they cause failure. More research needs to be done on how these discharges start and how their plasmas interact with the surrounding material and evolve to failure.

The phenomena of corona loss, radio and

television interference, and audible noise associated with overhead transmission lines all originate in electrical discharges around the lines and hence involve plasma physics. Moreover, as transmission voltage levels increase these phenomena tend to be more difficult to deal with. More basic information on plasma properties under conditions appropriate to transmission line operation would help in seeking ways to alleviate these problems.

Yet another application of plasma physics is in the spark gaps of a lightning arrester. Better understanding of the behavior of lightning arresters under a variety of conditions would result from better fundamental knowledge in plasma physics.

MATHEMATICS

To improve our ability to plan, operate, and control a power system we need to do research on new and improved mathematical techniques. Such areas as system modeling, control theory, probability and statistics, and digital computation need further research attention.

Work also needs to be done to improve our mathematical techniques in solving the boundary value problems that occur in electromagnetic theory, fluid flow, and heat transfer. These techniques will probably involve digital computation.

We also need more general mathematical techniques for studying relative system stability. Similarly we need more general techniques for contingency checking.

FLUID MECHANICS

In addition to those areas identified in some detail above as needing fundamental research, there are others that we will mention only briefly.

Fluid mechanical phenomena need to be better understood. Major areas where information is needed include steam and gas turbines and fossil and nuclear-fueled steam generators. The primary need is to be able to reduce the irreversibilities for improved efficiency, although other items such as fluid mechanical interaction with turbine blades which induces flutter also need to be studied.

EQUIPMENT NEEDS

To do effective research, the best equipment must be available to the researcher. In many cases the equipment exists and can be acquired; in other cases, research must be done to develop the equipment necessary to perform the desired research. An example of this occurred during the development of the vacuum circuit breaker when it was found necessary to work at vacuums well beyond the capability of existing vacuum gauges. Another research effort was necessary to develop a new vacuum gauge capable of the necessary measurements.

In most cases of fundamental research, complicated and expensive instrumentation is required along with technicians qualified to operate it. As in developing research scientists and engineers, it takes a lot of time to develop sophisticated instruments and to train people to operate them. Thus, research facilities and personnel training must be planned for well in advance of the time results are required.

MANPOWER AND EDUCATIONAL NEEDS

The work of the ERC R&D Goals Task Force has been to identify the available resources and how they are to be developed in order for utility systems to serve their customers more effectively. Most of the effort has been toward consideration of inanimate resources. A very important resource that we must assist in developing is the manpower needed not only for the R&D programs we define, but also for the planning, design, construction, and operating of the power systems of the future.

The kind of individual we need must be educated and motivated properly in school, given work experiences that further his education and training, and provided appropriate opportunities for continuing education throughout his career.

The electric utility industry, because of its great complexity, needs a variety of talents larger than any other industry. In its R&D programs it needs all varieties of scientists, biologists, chemists, physicists, mathematicians, social scientists, etc. In its planning operations it needs engineers of all sorts as well as urban planners and applied mathematicians. In the design and construction of new facilities and equipment it needs electrical, mechanical, nuclear, civil, chemical, and metallurgical engineers. The operation and maintenance of a power system requires all kinds of engineers as well as operations researchers and applied mathematicians. Throughout the organization there is need for personnel to apply computers and to manage the enterprise. In short, electric utilities need the services of almost every variety of professional available in our society.

The size of the R&D program we propose and the size and nature of the utility system we project for the future indicate a need for a large number of people with many talents. We must insure that the people we need will be available when we need them with something approaching optimum education and training. For this purpose we must engage in interactions with educational institutions in ways that will make clear our needs and assist the schools in meeting them.

Particularly effective in this regard will be utility system R&D acitivities on campus, teachers on leave working in utility systems, utility engineers on campus as participants in R&D programs, as visiting professors, and as participants in programs of continuing education.

In short, we cannot expect the manpower to be available in the numbers or with the talents desired unless we do something about it.

CHAPTER 8

ADMINISTRATION

PREAMBLE

Although not specifically enjoined to consider the organizational and administrative requirements of the extensive research effort outlined in this report, this Task Force feels constrained to address them, albeit briefly. For not only the size, universality and importance of this research task but its manifest centrality to the future of this country compels us to consider simultaneously with its substance and cost how it might be initially implemented. The discussion below represents our views on a possible administrative organization. However, this Task Force suggests that the ERC initiate an in-depth study to determine the best organization to implement the expanded research effort and the costs of administration. Such study should be undertaken along with the development of the funding program.

DISCUSSION

Currently, research is conducted by private utilities, electrical equipment manufacturers and Government agencies independently and in various combinations. Although there is often an integrated effort in some important programs with heavy financial support, the overall R&D effort is not fully coordinated. To avoid duplication of effort and to ensure that promising avenues of research are investigated, some electric utility industry-wide coordinating agency is needed.

In this respect, substantial progress has been made by the EEI and the ERC in developing industry-wide programs with broad support. With the manifold expansion and acceleration of research contemplated by this report, however, new organizational forms and streamlined administrative procedures would appear to be needed.

The Committee system now utilized by the ERC to conduct its research program has proven adequate to the task of administering relatively small programs where time is not of the essence. With the mounting pressures facing the industry today, the part-time Committee does not appear to be responsive enough. Nonetheless, building on the promising beginnings already made by the ERC would seem to be a prudent course.

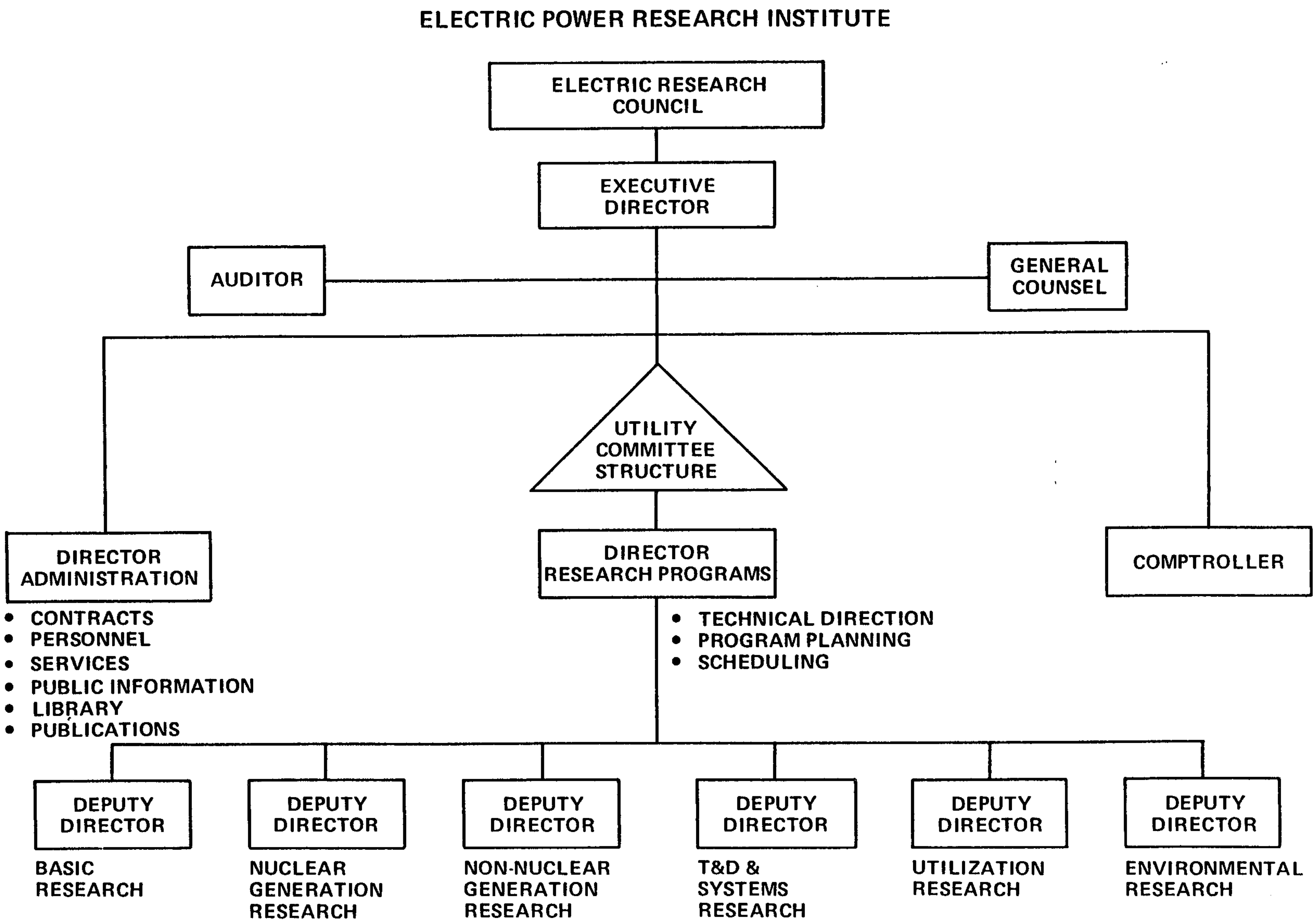
The inherent advantages of committees with their broad participation, involvement, and resources of expertise but only part-time commitment of key personnel should not be discarded. Rather the committee system should be retained and assigned roles for which it is best suited, i.e., development of broad programs and participation in advisory capacities. Married to this restructured committee system should be a full-time organization charged with the development of research plans and the vigorous implementation of programs.

The organization would house the professional staff necessary to develop broad coordinated research plans and programs for the electric utility industry. It would devise research strategy and translate these plans and strategy into specific research projects, suitably grouped under the guidance of appropriate industry-wide advisory committees. It would also include the small but highly professional contracting, financial and other necessary administrative staff to conduct the contract research programs.

ELECTRIC POWER RESEARCH INSTITUTE

The Electric Power Research Institute [EPRI] [a possible organizational chart is shown in the following figure] is designed to fulfill the requirements of such an organization. The ERC might be considered the Corporate Board of Directors with EPRI its action arm for not only contracting for research in prescribed areas, in accordance with approved priorities and available funds, but also coordinating overall electric utility industry programs.

The ERC Advisory Committees for each broad research area, drawing upon the top talent within the industry, would provide guidance and assistance, on a consultative basis, to the appropriate research divisions and subdivisions of EPRI. It is further contemplated that the Institute would be primarily an organization which prepared specifications; solicited proposals; negotiated and administered contracts; provided technical direction to contractors; received and disbursed funds; and developed research strategy, plans and programs, under the overall guidance of the Electric Research Council. The Institute would coordinate its activities with government agencies and manufacturers. Whether the Institute should conduct specific research projects, per se, requires further evaluation.



A POSSIBLE ELECTRIC UTILITY RESEARCH ORGANIZATION

R & D Goals Task Force Report
to the Electric Research Council,
June, 1971

FIGURE 7

APPENDIX A

PART I

FOREWORD

DEFINITION OF RESEARCH AND DEVELOPMENT [EXTRACT FROM FPC-UNIFORM SYSTEM OF ACCOUNTS FOR ELECTRIC UTILITIES]

"Research and development" means expenditures incurred by public utilities and licensees which represent research and development costs in the experimental or laboratory sense. Unless otherwise prescribed by the Commission, the definition of the term "research and experimental expenditures" contained in Internal Revenue Service Regulations, Section 1.174-2 or superseding revisions thereof, shall be the controlling definition for the purposes of this uniform system of accounts and the related annual report forms prescribed by the Commission. Terms in the general definition of the Internal Revenue Service regulations have been modified for this system of accounts. The term includes generally all such costs incident to the development of an experimental or pilot model, a plant process, a product, a formula, an invention, or similar property, and the improvement of already existing property of the type mentioned. The term does not include expenditures such as those for the ordinary testing or inspection of materials or products for quality control or those for efficiency surveys, management studies, consumer surveys, advertising, or promotions. However, the term includes the costs of obtaining a patent, such as attorney's fees expended in making and perfecting a patent application. On the other hand, the term does not include the costs of acquiring another's patent, model, production or process, nor does it include expenditures paid or incurred for research in connection with literary, historical, or similar projects.

Research and development expenditures include, in addition to the costs incurred by the public utilities and licensees for research or experimentation undertaken directly by them, expenses paid or incurred for research or experimentation carried on in their behalf by another person or organization (such as a research institute, foundation, engineering company, or similar contractor). However, any expenditures for research or experimentation carried on in behalf of public utilities and licensees by another person are not research and development expenses to the extent that they represent expenditures for the acquisition or improvement of land or depreciable property, used in connection with the research or experimentation, to which the public utilities and licensees acquire rights of ownership.

APPENDIX A

PART II

FOREWORD

DEFINITION OF RESEARCH AND DEVELOPMENT

[EXTRACT FROM INTERNAL REVENUE SERVICE REGULATIONS – SECTION 1.174-2]

[¶1969] § 1.174-2. Definition of research and experimental expenditures–(a) *In general.* (1) The term "research or experimental expenditures", as used in section 174, means expenditures incurred in connection with the taxpayer's trade or business which represent research and development costs in the experimental or laboratory sense. The term includes generally all such costs incident to the development of an experimental or pilot model, a plant process, a product, a formula, an invention, or similar property, and the improvement of already existing property of the type mentioned. The term does not include expenditures such as those for the ordinary testing or inspection of materials or products for quality control or those for efficiency surveys, management studies, consumer surveys, advertising, or promotions. However, the term includes the costs of obtaining a patent, such as attorneys' fees expended in making and perfecting a patent application. On the other hand, the term does not include the costs of acquiring another's patent, model, production or process, nor does it include expenditures paid or incurred for research in connection with literary, historical, or similar projects.

(2) The provisions of this section apply not only to costs paid or incurred by the taxpayer for research or experimentation undertaken directly by him but also to expenditures paid or incurred for research or experimentation carried on in his behalf by another person or organization (such as a research institute, foundation, engineering company, or similar contractor). However, any expenditures for research or experimentation carried on in the taxpayer's behalf by another person are not expenditures to which section 174 relates, to the extent that they represent expenditures for the acquisition or improvement of land or depreciable property, used in connection with the research or experimentation, to which the taxpayer acquires rights of ownership.

(3) The application of subparagraph (2) of this paragraph may be illustrated by the following examples:

Example (1). A engages B to undertake research and experimental work in order to create a particular product. B will be paid annually a fixed sum plus an amount equivalent to his actual expenditures. In 1957, A pays to B in respect of the project the sum of $150,000 of which $25,000 represents an addition to B's laboratory and the balance represents charges for research and experimentation on the project. It is agreed between the parties that A will absorb the entire cost of this addition to B's laboratory which will be retained by B. A may treat the entire $150,000 as expenditures under section 174.

Example (2). X Corporation, a manufacturer of explosives, contracts with the Y research organization to attempt through research and experimentation the creation of a new process for making certain explosives. Because of the danger involved in such an undertaking, Y is compelled to acquire an isolated tract of land on which to conduct the research and experimentation. It is agreed that upon completion of the project Y will transfer this tract, including any improvements thereon, to X. Section 174 does not apply to the amount paid to Y representing the costs of the tract of land and improvements.

(b) *Certain expenditures with respect to land and other property.* (1) Expenditures by the taxpayer for the acquisition or improvement of land, or for the acquisition or improvement of property which is subject to an allowance for depreciation under section 167 or depletion under section 611, are not deductible under section 174, irrespective of the fact that the property or improvements may be used by the taxpayer in connection with research or experimentation. However, allowances for depreciation or depletion of property are considered as research or experimental expenditures, for purposes of section 174, to the extent that the property to which the allowances relate is used in connection with research or experimentation. If any part of the cost of acquisition or improvement of depreciable property is attributable to research or experimentation (whether made by the taxpayer or another), see subparagraphs (2), (3), and (4) of this paragraph.

(2) Expenditures for research or experimentation which result, as an end product of the research or experimentation, in depreciable property to be used in the taxpayer's trade or business may, subject to the limitations of subparagraph (4) of this paragraph, be allowable as a current expense deduction under section 174(a). Such expenditures cannot be amortized under section 174(b) except to the extent provided in paragraph (a) (4) of § 1.174-4.

(3) If expenditures for research or experimentation are incurred in connection with the construction or manufacture of depreciable property by another, they are deductible under section 174(a) only if made upon the taxpayer's order and at his risk. No deduction will be allowed (i) if the taxpayer purchases another's product under a performance guarantee (whether express, implied, or imposed by local law) unless the guarantee is limited, to engineering specifications or otherwise, in such a way that economic utility is not taken into account; or (ii) for any part of the purchase price of a product in regular production. For example, if a taxpayer orders a specially-built automatic milling machine under a guarantee that the machine will be capable of producing a given number of units per hour, no portion of the expenditure is deductible since none of it is made at the taxpayer's risk. Similarly, no deductible expense is incurred if a taxpayer enters into a contract for the construction of a new type of chemical processing plant under a turn-key contract guaranteeing a given annual production and a given consumption of raw material and fuel per unit. On the other hand, if the contract contained no guarantee of quality of production and of quantity of units in relation to consumption of raw material and fuel, and if real doubt existed as to the capabilities of the process, expenses for research or experimentation under the contract are at the taxpayer's risk and are deductible under section 174(a). However, see subparagraph (4) of this paragraph.

(4) The deductions referred to in subparagraphs (2) and (3) of this paragraph for expenditures in connection with the acquisition or production of depreciable property to be used in the taxpayer's trade or business are limited to amounts expended for research or experimentation. For the purpose of the preceding sentence, amounts expended for research or experimentation do not include the costs of the component materials of the depreciable property, the costs of labor or other elements involved in its construction and installation, or costs attributable to the acquisition or improvement of the property. For example, a taxpayer undertakes to develop a new machine for use in his business. He expends $30,000 on the project of which $10,000 represents the actual costs of material, labor, etc., to construct the machine, and $20,000 represents research costs which are not attributable to the machine itself. Under section 174(a) the taxpayer would be permitted to deduct the $20,000 as expenses not chargeable to capital account, but the $10,000 must be charged to the asset account (the machine).

(c) *Exploration expenditures.* The provisions of section 174 are not applicable to any expenditures paid or incurred for the purpose of ascertaining the existence, location, extent, or quality of any deposit of ore, oil, gas or other mineral. See sections 615 and 263. [Reg. § 1.174-2.]

APPENDIX B

PART I

CHAPTER 2 – ENERGY CONVERSION

This Appendix presents a detailed description of all recommended research projects for energy conversion including estimated costs and schedules.

Method of Generation: Breeder Reactors

Priority: 1 – Critically Important

Description: Breeder reactors utilize neutrons produced in fission reactions to bombard blanket materials, thereby creating a new fissionable material. Since the schemes under investigation produce more than one neutron per fission, there are sufficient numbers of neutrons available to sustain the fission chain reaction and to produce significant amounts of new fissionable material. Power is extracted from the reactor in a conventional manner.

Benefits and Goals: Breeder reactors will have a marked impact on the fuel situation. Fuel reserves will be greatly conserved and enrichment capacity will no longer be critical as the breeder reactors will be producing fissionable fuels – enough for themselves and another reactor of equal size approximately every 7-10 years.

Status of Work: There is presently and has been for some years a good deal of work in the field of breeder reactors. Principally, the AEC and the industry have been supporting the Liquid Metal Fast Breeder Reactor (LMFBR). Other concepts have been proposed, however, and there is work going on to investigate Molten Salt Breeder Reactors, Gas Cooled Fast Reactors, and Light Water Breeder Reactors.

Significant Obstacles: The chief immediate problem is to raise funds and begin construction of a demonstration plant to prove the present technology. There will be difficult problems of site selection for breeders. Additional problems, primarily due to the higher enrichment of the fuel than for thermal reactors, are ability to license, plant safety, shipping of spent fuel, and disposal of more radioactive wastes.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
250	340	369	427	432	476	415	331	208

1981 to 1985	1986 to 1990	1991 to 2000
500	250	200

by function:

Demonstrations *	– $1,250 million – three plus Fermi
Continuing Research	– $2,948 million
Total	– $4,198 million – 29 Years

*Capital costs in excess of power value

Method of Generation: Nuclear Fusion

Priority: 1 – Critically Important

Description: Confinement of heavy isotopes of hydrogen (deuterium and/or tritium) at sufficiently high temperature and density, and for a long enough time will result in the fusion of these isotopes to produce a heavier element and the release of a large amount of energy. Conversion of this energy to electricity is the method of power production by means of a nuclear fusion reaction.

Benefits and Goals: The fuel required for the fusion reaction (deuterium) is naturally abundant. If a D-T reaction is used, the tritium required could be taken from a tritium inventory at first and, in the future, the tritium could be "bred" during the fusion reaction. Higher efficiencies are possible if topping cycles can be used to extract high quality energy and adverse environmental impact will be minimal. In addition, the chance for a nuclear excursion will be impossible.

Status of Work: In recent years, important strides have been made toward setting up the conditions required for the thermonuclear fusion reaction. Large scale efforts have been going on both in this country and abroad and the scientists seem to agree that a controlled thermonuclear reaction will be demonstrated by the mid 1970's., with satisfactory funding.

Significant Obstacles: The chief problem at this stage is to actually sustain a thermonuclear reaction. Additional problems are: design of vacuum wall, avoiding escape of tritium, lithium blanket design, chemical and safety aspects of handling liquid lithium, fuel injection system, spent gas removal system, magnet design and tritium handling.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
50	60	95	110	135	160	170	215	245

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
1000	1000	500	500

by function:

Basic Research	– $1,240 million
Pilots	– $ 300 million – Late 1970's
Demonstration	– $1,000 million – By Mid 1980's
Continuing Research	– $1,700 million
Total	– $4,240 million – 29 Years

Project:	R&D on Present Methods of Generation
Priority:	1 – Critically Important
Description:	Work to improve the reliability and efficiency of present day equipment must be continued. Because the units on the line today will be in our generation mix for many years to come, it is essential that all possible improvements be made on these units to make them more efficient, reliable, and acceptable to the public. This work must continue on nuclear generators as well as fossil, including fluidized bed combustion.
Benefits and Goals:	Because of the heavy industry-wide investment in present day equipment, it is essential that any and all possible improvements be realized. Operating savings and reduced environmental impact would be hoped for.
Status of Work:	For many years past and up to this time, leading manufacturers have been seeking ways to improve their products. These efforts have involved substantial sums of money which would be expected due to the heavy industry investment in generating equipment. It is expected that such work will continue.
Significant Obstacles:	Materials problems have been defined in many instances. Work to develop materials capable of handling the severe stresses which they face in operation is underway. On the nuclear side, fuel handling and cycling problems are being investigated along with safety requirements for nuclear power plants.

Timetable and Expenditures (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
165	180	195	210	225	240	255	270	285

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
1,650	2,025	2,400	2,775

Total – $10,875 million – 29 Years

Method of Generation: Fuel Processing

Priority: 1 – Critically Important

Description: Gasification and solvent processing of coal, and hydrogen production (to be used as fuel) are proposed to provide high quality clean fuels for generating plants. The refined coal products are projected to be economically attractive in the fuel market. Transmission of hydrogen by pipeline to the point of use could be an attractive prospect in the future as natural gas fuels dwindle.

Benefits and Goals: Greatly reduced pollution from the combustion of these refined fuels is projected. Higher heat rate and ease of transportation of the fuel to the point of use are predicted benefits which will add to the economic attractiveness of these processes.

Status of Work: There is a great deal of interest in these processes and considerable work is going on under the auspices of the Federal Government. Mid 1970 dates of development have been targeted and progress is steady.

Significant Obstacles: Gasification and solvent processing techniques are being perfected. Areas of poor understanding have been identified and work in these areas is underway to improve the techniques.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
8	10	10	15	10	6	2	2	2

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
5	5	–	–

by function:

Basic Research	– $ 6 million
Pilot Models	– $16 million
Demonstration	– $45 million
Continuing Research	– $ 8 million
Total	– $75 million – 19 Years

Method of Generation:	Magnetohydrodynamics (MHD) – open cycle
Priority:	2 – Very Important
Description:	An MHD generator converts the kinetic and thermal energy of a moving plasma directly into electrical energy by passing the "seeded" flow through a strong magnetic field. Seeding is required to produce high conductivity in the gas flow. The MHD unit will probably be used to "top" a conventional steam cycle. Fully developed, 50% or more of the total output power of the combined cycle will be extracted from the MHD portion.
Benefits and Goals:	MHD is proposed for fossil fired, central station, base load power production. Peaking power MHD plants would likely be spun off from an MHD developmental program. Increased cycle efficiencies are projected, resulting in significant decreases in thermal pollution. Higher combustion temperatures should facilitate flue-gas cleanup (essential to the process in order to recover expensive seed material) and could provide economies resulting from the sale of refined waste products. Increased efficiency will also help alleviate projected fossil fuel shortages by requiring less fuel for the generation of a given number of kilowatthours than present day generators.
Status of Work:	MHD technology is well advanced, both in this country and abroad. Engineering solutions to many problems encountered have been found. Significant efforts have been carried on in the decade of the 60's, providing much insight into problem areas and potential problems of open cycle MHD. It has been reported that the Russians have started up the MHD portion (25 MW) of a 75 MW combined cycle plant early this year.
Significant Obstacles:	Problems encountered in the burning of coal in an MHD generator are presently not well understood. The effects of the combustion products on generator performance and lifetime need to be investigated. Preheater technology and methods of highly efficient stack-gas cleaning are other areas in which significant work is required for MHD base load plants.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
4.2	4.4	4.7	9.5	16.2	14.4	5.0	4.5	30.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
120.0	25.0	–	–

by function:

Basic Research	– \$ 12.3 million
Pilot	– \$ 39.0 million
Demonstration	– \$150.0 million
Continuing Research	– \$ 36.6 million
Total	– \$237.9 million – 19 Years

Method of Generation:	Fuel Cells
Priority:	2 – Very Important
Description:	The fuel cell intended for substation application and installation at isolated locations on distribution circuits would utilize a fossil fuel, air, and water. These would be processed and sent to the hydrocarbon-air fuel cell where chemical reactions would produce dc power. Resultant waste products would be air, water, and heat which could be recycled for the most part in the fully developed system.
Benefits and Goals:	The chief goal of fuel cells for substation use is to provide economic generation at dispersed locations on a power system in 10-20 MW blocks. Reduced physical plant investment in transmission lines (resulting in environmental improvement), centralized base-load generating plants, and substation equipment will help provide economic incentive for this method. Air pollution problems should be eased by the employment of fuel cells because of (1) reduced emissions from the cells themselves, and (2) "scattered" sources of emissions. Because of probable modular construction, high reliability can be attained from these units. Siting problems could be minimized if, as predicted, fuel cells could be located in urban areas and areas where water is scarce.
Status of Work:	Fuel cells have been developed for use in the United States space program. These were hydrogen-oxygen cells, much too costly and inefficient for power system application. The technology is, however, in hand for the development of hydrocarbon-air fuel cells, and considerable work is presently being carried on in the United States.
Significant Obstacles:	Developing multi-fuel capabilities, achieving higher voltage output, interfacing with electric utilities, meeting desired economic design criteria and operating endurance are the areas of fuel cell development requiring the most effort.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
6.5	8.0	4.0	4.0	3.0	2.0	2.0	2.0	2.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
5.0	–	–	–

by function:

Basic Research	– $ 9.4 million	
Pilot Plants	– $ 8.6 million	
Demonstration	– $10.5 million	– By late 1970's
Continuing Research	– $10.0 million	
Total	– $38.5 million	– 14 Years

Method of Generation: Bulk Electric Storage Batteries

Priority: 2 – Very Important

Description: Bulk electric storage batteries envisioned for use on power systems would serve a purpose similar to that of pumped storage. During "off-peak" hours, low cost power would be used to charge the batteries (made of materials capable of storing large amounts of power). During peak conditions, the batteries would be connected to the system for power production.

Benefits and Goals: The development of large energy storage batteries would allow more efficient use for installed generating equipment and would eliminate the need of relatively inefficient steam and gas turbines for peaking power. If charged by means of base-load nuclear plants, air pollution would not be associated with this peak power. Dispersed siting near load centers and perhaps even in the cities would be possible with bulk storage batteries.

Status of Work: Most of the work done to date on bulk energy storage batteries has been single cell experiments. Many combinations of electrodes and electrolytes are being tested for maximum energy density, acceptable high temperature performance characteristics, etc. Problem areas are still being identified and actual batteries have not as yet been built. This technology is in its infancy.

Significant Obstacles: Among those problems already identified in storage battery research are materials corrosion at high temperatures, incomplete discharge, and large voltage drops at the electrodes. Systems engineering problems have not been identified at this time, but they are expected to be encountered when we try to incorporate large batteries into our generation mix on the power systems.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
5.0	5.0	6.0	6.0	4.0	4.0	5.0	5.0	5.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
5.0	10.0	–	–

by function:

Basic Research	– \$ 8.0 million
Pilot Models	– \$15.0 million
Demonstration	– \$20.0 million – By early 1980's
Continuing Research	– \$17.0 million
Total	– \$60.0 million – 19 Years

Method of Generation: Unconventional Cycles

Priority: 3 – Important

Description: The use of helium or CO_2 as a working fluid instead of conventional steam, or the use of two working fluids (e.g., potassium and steam) in the power cycle allows for the rise of higher temperatures and pressures in the plant cycle. For the case of the potassium binary cycle or the helium cycle, special turbines would be required for the power extraction from these fluids. In the binary cycles, the balance of plant is conventional steam.

Benefits and Goals: Unconventional cycles utilizing working fluids other than steam offer increased efficiencies, for the most part, for present day plant designs. Higher efficiencies result in savings of operating dollars and reduced thermal waste. Problems with corrosion are lessened or eliminated by the use of CO_2 or helium in conventional cycles. Binary plants offer increases in efficiency on the order of 15% since power is extracted from high quality heat before the fluid produces steam for the conventional steam cycle, that steam at modern day conditions.

Status of Work: A good number of studies and some tests have been performed on these unconventional cycles. Problem areas have been identified and some engineering solutions have been proposed. Much of this work is interesting because of the capability shared by several of these methods to extract power from very high temperature fluids, making the concepts applicable (perhaps) to high temperature nuclear reactors.

Significant Obstacles: Design, development, and testing of new turbines, shaft seals, condensers, etc. would be required for some of the proposed concepts. Effects of the working fluid on life-time of all equipment would require investigation. There are no apparent technological roadblocks to impede the development of any or all of these unconventional cycles.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
6.0	6.0	9.0	9.0	6.0	4.5	3.0	3.0	3.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
7.5	–	–	–

by function:

Basic Research	– $11.0 million	
Pilot Models	– $30.0 million	– By late 1970's
Demonstration	– –	
Continuing Research	– $16.0 million	
Total	– $57.0 million	– 14 Years

Method of Generation:	Solar Energy Conversion
Priority:	4 – Desirable
Description:	Conversion of the sun's energy to electric energy can be accomplished either directly through photovoltaic cells or indirectly by means of collecting and focusing this energy to a point. In the former method, solar cells convert a portion of the energy incident to them by means of voltage differences between materials of the cell. In the latter method, the sun's energy is used to produce steam, which is then sent through a conventional steam plant.
Benefits and Goals:	Solar energy conversion offers free fuel and greatly reduced environmental intrusion. Large land area requirements would be the only intrusion by a scheme utilizing photovoltaic cells for the direct conversion.
Status of Work:	Virtually all of the work done on the development of solar energy conversion schemes has been done in connection with the United States space program. Satellites are currently being powered by solar cells. Only recently have the efforts of the scientists and engineers in the solar energy conversion field been turned toward the commercial application of solar cells.
Significant Obstacles:	Discouragingly low efficiencies (on the order of 10%) of present day solar cells, and the very high cost of producing these cells are the two most significant obstacles. Low efficiency requires huge land area for a sizable power plant. Increasing the efficiency of the cells to 20% (as some feel possible) would reduce the land area required for the same plant by 50%. Development of auxiliary equipment for fully developed plants is another area where significant work is required.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
3.0	3.0	4.0	4.0	4.0	8.0	10.0	15.0	17.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
45.0	30.0	15.0	10.0

by function:

Basic Research	– $ 22.0 million	
Pilot Models	– $ 20.0 million	– Late 1970's
Demonstration	– $ 50.0 million	– Mid 1980's
Continuing Research	– $ 76.0 million	
Total	– $168.0 million	– 29 Years

Method of Generation:	Magnetohydrodynamics (MHD) – liquid metal
Priority:	4 – Desirable
Description:	The differences between a liquid metal MHD generator and a plasma MHD generator are basically two: (1) the working fluid; and (2) the method of power extraction. In a liquid metal MHD unit, the power is extracted as alternating current by taking advantage of the difference in velocity between the fluid and the applied magnetic field.
Benefits and Goals:	Liquid metal MHD appears promising since, due to its operation at lower temperatures, no significant materials breakthroughs seem to be required for its development. Used as a topping cycle, this concept would afford increased efficiency with its related benefits.
Status of Work:	Work done in the past has shown that power can be extracted from an induction liquid metal MHD generator. However, predicted efficiencies and performance have not been reached for a number of reasons. Some work on this concept is still continuing, both in the U.S. and abroad.
Significant Obstacles:	Problems with generator performance have been uncovered during model testing of these generators. Failure to completely understand and compensate for these difficulties has resulted in an inability to attain the level of performance predicted for this concept. Specifically, claimed increases in efficiency have not been realized in units suitable for power system application. Increased understanding of the systems engineering problems and component problems is necessary.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
0.3	0.8	0.8	1.0	1.0	2.0	2.0	5.0	5.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
10.0	5.0	–	–

by function:

Basic Research	– $ 7.4 million	
Pilot Models	– $ 3.0 million	
Demonstration	– $10.0 million	– By Mid 1980's
Continuing Research	– $12.5 million	
Total	– $32.9 million	– 19 Years

Method of Generation:	Magnetohydrodynamics (MHD) – Closed cycle plasma
Priority:	4 – Desirable
Description:	The basic principle underlying the operation of closed cycle plasma MHD is the same as that for open cycle MHD – conversion of thermal and kinetic energy of the flowing plasma to electric power. Seeding of the plasma is not required (but is sometimes used) for this concept since high conductivity is attained by means of "non-equilibrium thermal ionization" of the hot gas. Lower temperatures are required for this method than are necessary for open cycle operation.
Benefits and Goals:	The closed cycle concept is aimed at a central station, base load application. Its use for topping a nuclear cycle is proposed, thus allowing the use of the very high quality heat available from the reactor cores. Increased overall cycle efficiencies are, therefore, the chief benefit to be realized from this concept. Associated environmental effects (i.e. decreased thermal pollution) and economic benefits are predicted as a result of the higher efficiency.
Status of Work:	Much laboratory work has been carried on in both the United States and abroad to investigate the properties of the plasma in the non-equilibrium ionization mode. Problems have been encountered in maintaining the stability of the plasma under this condition. However, recent investigations abroad have been aimed at determining the criticality of maintaining plasma stability. Early results seem to indicate operation of a closed cycle plasma MHD generator may be possible even with plasma instabilities. This work is proceeding.
Significant Obstacles:	At present, the plasma stability problem is still considered to be the most difficult concern. The engineering problems associated with the topping of a nuclear reactor have not been explored in depth, and this could prove to be a difficult problem.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.5	2.5

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
25	45	20	10

by function:

Basic Research	– $ 6.0 million	
Pilot Models	– $ 12.5 million	– By Early 1980's
Demonstration	– $ 66.5 million	– By Late 1980's
Continuing Research	– $ 30.0 million	
Total	– $115.0 million	– 29 Years

Method of Generation:	Thermionic Conversion
Priority:	4 – Desirable
Description:	Thermionic converters utilize heat applied to an electrode to "boil off" electrons. The electrons cross a gap, usually occupied by a highly conductive vapor such as cesium, and are collected on a cooler electrode. Power is extracted from the process by connecting a load between the emitter and the collector, allowing the higher potential electrons at the collector to flow through the load back to the emitter, thus completing the circuit.
Benefits and Goals:	The thermionic converter is proposed as a topping cycle for either nuclear of fossil-fired plant. In either case, the converter would be very near the heat source (in the reactor or furnace) and rejected heat (cooling the collector) would be transferred to the working fluid of a conventional cycle. Higher efficiencies are projected and the thermionic converter itself would cause no pollution problems, bringing about a reduction in overall plant waste heat, and savings in capital investment on the power system.
Status of Work:	Studies have been done to show the expected magnitude of increased efficiencies when the converter is applied on a coal fired unit. 10% increases have been projected. In-core reactor studies and tests are currently underway. Similar efficiency increases are projected for this application.
Significant Obstacles:	The effect of a coal environment on the thermionic converter electrodes could be a problem. Relatively few hours have been accumulated by electrodes in a coal environment, leaving an incomplete knowledge of the problem. Radiation damage to insulators and the accumulation of fission products on the electrodes are problems with the in-core approach. Fundamental tests investigating these areas could prove fruitful.

Timetable and Costs for Development (Millions of 1971 Dollars):

by period:

1972	1973	1974	1975	1976	1977	1978	1979	1980
1.0	1.0	2.0	2.0	3.0	3.0	2.0	2.0	1.0

1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
2.5	2.5	–	–

by function:

Basic Research	– $ 6.5 million
Pilot Models	– $ 2.5 million – Early 1980's
Demonstration	–
Continuing Research	– $13.0 million
Total	– $22.0 million – 19 Years

Method of Generation: Geothermal and Air Storage Peaking.

Priority: Suggested for Private Support

Description: The methods named above have a potential place in electric powe generation of the future. However, due to specific requirements fo the several concepts, their application is limited to certain geographi segments of the country.

Benefits and Goals: Each concept offers its own unique advantages and all appear to b feasible under the conditions dictated for their application.

Status of Work: Feasibility has been shown and work is currently underway to eithe sell or develop these methods.

Significant Obstacles: Suitability and applicability to relatively minor segments of th industry do not appear to warrant industry-wide participation in th development of these concepts.

Timetable and Costs for Development:
No recommendation.

APPENDIX B

PART II

INFORMATION SOURCES FOR CHAPTER 2
ENERGY CONVERSION

NUCLEAR FUSION

1. Alexander, Tom; "The Hot New Promise of Thermonuclear Power," Fortune, June 1970
2. Drew, H. R., and Drummond, W.E.; "Power From Nuclear Fusion – Problems and Promises," paper presented at American Power Conference, 33rd Annual Meeting, Chicago, April 20-22, 1971
3. Forsen, H.K.; "On the Problems of Fusion Engineering," University of Wisconsin, January 1971
4. Fraas, A.P., and Postma, H.; "Preliminary Appraisal of the Hazards Problems of a D-T Fusion Reactor Power Plant." Oak Ridge National Laboratory – USAEC, November 1970
5. "Fusion Technology." Energy 1970, Las Vegas, Nevada, September 1970
6. Gough, William C., and Eastland, Bernard J.; "The Prospects of Fusion Power." *Scientific American,* February 1971
7. Gould, R.W., Furth, H.P., Post, R.F. and Ribe, F.L.; "Progress in Controlled Thermonuclear Research."
8. "Progress in Fusion Held to Warrant an Upswing in Funding." *Nuclear Industry,* January 1971
9. Rose, D.J.; "Engineering Feasibility of Controlled Fusion." *Nuclear Fusion,* September 1969
10. Summary Report of Informal Working Study Week on Nuclear Fusion Reactors. Culham Laboratory, Abingdon, Berkshire, England. September 22-26, 1969

BREEDER REACTORS

1. "Cost Benefit Analysis of the U.S. Breeder Reactor Program." U.S. AEC – WASH 1126, April 1969
2. "Potential Nuclear Power Growth Patterns." U.S. AEC – WASH 1098, November 1969

3. Shaw, Milton, et. al., Text of statement of AEC staff to JCAE, March 4, 1971
4. "Reactor Development Finding." *Nuclear Industry*, a publication of Atomic Industrial Forum, March 1971
5. "Report of the EEI Reactor Assessment Panel." Edison Electric Institute Publication No. 70-30, April 1970
6. "Fast Breeder Reactor Report." Edison Electric Institute Publication No. 68-28, May 1968
7. Demonstration plant proposals and related publications of LMFBR manufacturers [proprietary information], Atomics International, General Electric, and Westinghouse.
8. "Light Water Breeder Reactor [LWBR] Program", prepared by Naval Reactors Branch, U.S. AEC, 1969
9. Packet of material on molten salt reactors provided to the R&D Goals Task Force by M.W. Rosenthal, Oak Ridge National Laboratory which included:
   - an article from the June 1969 issue of *Science Journal.*
   - a review of molten salt reactor technology, *Nuclear Application and Technology*, February 1970
   - *Power Engineering:* pp. 42-44, August 1970
   - "A Program for the Development of Molten Salt Breeder Reactors", ORNL, June 24, 1968
10. Gulf General Atomic publications and reports on the Gas Cooled Fast Breeder Reactor [GCFR] including:
    - GCFR presentation to the EEI Reactor Assessment Panel, July 29, 1969
    - "GCFR/The Gas Cooled Fast Breeder Reactor"
    - Blumeyer, M.C., and Peak, John C., "The Breeder Reactor in Your Future – The GCFR", GA9960, March 27, 1970
    - Melese-d'Hospital, Gilbert, "Advanced Fast Breeder Reactors with Gas Cooling", GA-8833, September 27, 1968
11. "Proposal to the U.S. AEC for Utilization of the Enrico Fermi Atomic Power Plant" prepared by Power Reactor Development Corp., November 16, 1970 [revised December 30, 1970]

FUEL CELLS

1. "Fuel Cells for Central Power Generation." D.H. Archer, *Mechanical Engineering*, March 1968
2. "The Design of a 100-Kilowatt, Coal Burning, Fuel Cell Power System." D.H. Archer and R.L. Zahradnik, *Chemical Engineering Progress Symposium* Series, Volume 63, Number 75, 1967
3. "Westinghouse Solid-Electrolyte Fuel Cell." D.H. Archer and others, *Advances in Chemistry Series*, Number 47, 1965
4. "A Coal Burning Solid Electrolyte Fuel Cell Power Plant." R.L. Zahradnik and others, *Advances in Chemistry Series*, Number 47, 1965.
5. "Powercels* for Electric Utility Systems", Pratt and Whitney Aircraft, Division of United Aircraft Corporation, January, 1971 and February, 1971

6. "Fuel Cells and Their Future Prospects", K.V. Kordesch, IEEE Conference Paper, 70CP-213-PWR, 1970
7. Information received from Westinghouse and Pratt and Whitney Aircraft.

MAGNETOHYDRODYNAMICS

1. "MHD for Central Station Power Generation: A Plan for Action", OST Report by Panel on MHD, June 1969
2. "Recent Studies of Advanced Coal Burning Power Plants", W.E. Young and others, Publication and Date unknown.
3. "MHD – Steam Central Station Power", J.B. Dicks and others, Publication and Date unknown.
4. "MHD Power Generators in Central Stations", T.C. Tsu, *IEEE Spectrum,* June 1967
5. "The MHD Combined Cycle", W.E. Young and others, *Mechanical Engineering,* November 1967
6. "MHD Generators with Nonequilibrium Ionization", J.L. Kerrebrock, *AIAA Journal,* 1965
7. "Conditions for Useful Operation of MHD Generator Ducts in the Non-Equilibrium Ionization Mode", M.E. Talaat, Publication and Date unknown.
8. "The Steady State Controlled Discharge Linear Non-Equilibrium Magnetogasdynamic Generator", N.A. Evans, Publication and Date unknown.
9. "Fluid-Metal MHD/Steam Binary Cycle Developed", L.L. Prem, *Electrical World,* October 1964
10. "Fluid Metal MHD/Binary Cycle Power Generation", L.L. Prem, and T.C. Wang, Publication and Date unknown.
11. "Fluid Metal MHD-Steam Binary Plant Economy for Central Stations", L.L. Prem, Publication and Date unknown.
12. "Technology of Magnetohydrodynamics – Final Technical Report", L.L. Prem and others, prepared for USAERG, October 1968
13. "Proposal for a National MHD Power Generation Program", the MHD Group at AVCO Everett Research Laboratories, June 1970
14. "Combustion – MHD Power Generation for Central Stations", L.P. Harris and G.E. Moore, IEEE Transaction Paper 71TP79-PWR, January 1971
15 *Magnetohydrodynamic Energy Conversion,* R.J. Rosa, McGraw-Hill Book Company, 1968
16. Open Cycle MHD Power Generation, J.G. Heywood and G.J. Womack, Pergamon Press, 1969
17. Information received from Dr. W.D. Jackson of AVCO, Everett.

SOLAR POWER

1. "The Potential of Solar Power and Heat", P.E. Glaser and G.O.G. Lof, IEEE Conference Paper, 1971
2. Information from Walter E. Morrow, MIT; Prof. P.H. Fang, Boston College; Peter E. Glaser, Arthur D. Little, Inc.

THERMOELECTRIC POWER

Information from: C.E. Backus, Arizona State University; R. Carpenter, U.S. Atomic Energy Commission; S.C. Cohen, Gulf General Atomics, Incorporated; J.F. Engelberger, Energy Research Corporation; G.N. Hatsopoulos, Thermo Electron Corporation; V. Raag, RESALB Scientific; S. Seiken, U.S. Atomic Energy Commission

THERMIONIC POWER

Information gained from same list as above for Thermoelectric Power.

GEOTHERMAL POWER

Information received from Ira Klien, U.S. Bureau of Reclamation.

TIDAL POWER

"Tidal Power", *Energy International,* Date unknown.

BULK ELECTRIC STORAGE BATTERIES FOR EMERGENCY AND PEAKING

Information received from W.V. Botts, Atomics International.

COMBINED CYCLES

1. "Conceptual Design of an Oil-Fired Potassium – Steam Gas Turbine Ternary Cycle", A.P. Fraas, Internal Report at ORNL
2. "A Potassium-Steam Binary Vapor Cycle for a Molten-Salt Reactor Power Plant", *Transactions of the ASME,* Journal of Engineering for Power, 1966
3. "A Potassium-Steam Binary Vapor Cycle for Nuclear Power Plants", A.P. Fraas and others, Oak Ridge National Laboratory Report, May 1964
4. Information from A.P. Fraas, Oak Ridge National Laboratory.

MISCELLAENOUS

Air Storage:

1. "220-MW Air Storage Power Plant", E.K.A. Olsson, *ASME Publication,* 70-GT-34.
2. Information from ASEA, Incorporated, George M. Vickers.

EGD:

1. "Prospects of Electrogasdynamic Power Generation", J.R. Melcher and T.C. Cheng, IEEE Conference Paper, 70CP210-PWR.
2. "Separate Evaluations of EGD Power Generation", Office of Coal Research, Research and Development Report Number 35, prepared by Dynatech Corporation, IIT Research Institute, and Iowa State University, 1967 and 1968

NPNE:

"NPNE Powered Electrical Peaking Plant", Rocketdyne, a Division of North American Rockwell, 1971

Feher Cycle:

"Study of Feher Cycle Application to Large Electric Power Generating Plants", Astropower Laboratory of McDonnell Douglas Astronautics Company, March 1969

PUMPED STORAGE HYDRO

Information received from E. Baxter, U.S. Bureau of Reclamation.

GENERAL BACKUP REFERENCES

Presentations prepared by:

Atomics International
General Electric Company
Westinghouse Electric Corporation

presented at the ERC R&D Goals Task Force meeting in New Orleans, January 1971

APPENDIX C

CHAPTER 3
TRANSMISSION AND DISTRIBUTION

This Appendix presents a summary of recommended transmission and distribution research projects including estimated costs and schedules.

TABLE C-I

SUMMARY OF TRANSMISSION AND DISTRIBUTION R&D COSTS BY PRIORITY

(Millions of 1971 Dollars)

RANKING	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
Priority 1	100.7	112.2	131.1	137.4	119.2	109.0	103.9	108.7	110.9	575.1	682.0	1741.8	4032.0
Priority 2	5.0	5.5	8.1	9.0	7.8	7.5	7.2	6.5	5.3	12.9	11.6	7.6	94.0
Priority 3	2.3	3.9	4.9	7.6	10.9	10.2	8.5	7.5	7.2	36.4	11.9	2.5	113.8
Priority 4	2.1	1.8	2.6	3.2	6.1	7.3	7.2	6.7	6.4	45.7	28.6	2.5	120.2
TOTAL	110.1	123.4	146.7	157.2	144.0	134.0	126.8	129.4	129.8	670.1	734.1	1754.4	4360.0
Unassigned	—	—	—	—	12	26	33	38	38	243	302	720	1412
TOTAL Including Unassigned	110	123	147	157	156	160	160	167	168	913	1036	2474	5772

R&D GOALS TASK FORCE REPORT TO THE
ELECTRIC RESEARCH COUNCIL, JUNE, 1971

TABLE C-II

AC UNDERGROUND TRANSMISSION

(Millions of 1971 Dollars)

PRIORITY	PROJECT	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
1	Test Facilities –Waltz Mill Test Station –DC Test Station Installation & Operation	5.5	4.5	4.8	4.5	5.9	5.0	5.0	5.0	5.0	19.0	19.0	35.5	118.7
1	HV and EHV Cable Systems –HV Extruded Dielectric Cable Development –Synthetic Insulation EHV Cables –Gas Insulated Cable Systems	6.8	6.5	7.0	7.5	3.3	2.5	2.5	2.5	2.5	3.3	—	—	44.4
1	Cryogenic Cables –AC Superconducting Cable at Liquid He Temperature-Dev., Fabrication, Field Testing –Resistive Cryogenic Systems	4.3	4.3	4.5	5.8	2.8	2.8	2.5	2.5	2.5	4.0	3.3	2.8	42.1
2	Ambient Control –Low Viscosity Oil Systems –Refrigerator System Optimization –Heat Pipes & Thermal Syphons	1.0	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.3	1.3	—	6.2
2	Installation Methods	2.5	2.0	2.3	1.3	0.8	0.8	0.8	0.8	0.8	2.0	2.0	3.8	19.9
3	Basic Studies System Analysis AC Vacuum Insulation Dielectric Phenomena –Dielectric Phenomena in Two-Phase Insulation Systems –High Frequency Transmission Systems - Basic & Applied Studies	1.8	1.5	1.5	1.5	3.8	3.8	3.8	3.8	3.8	25.5	1.3	2.5	54.6
3	Cable Accessories –Simplified Jointing Techniques –High Capacity Potheads –Non-magnetic Pipe-Type Cable Systems	0.5	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.0	—	9.0
4	Materials Development –Polymeric Paper Cable Insulation –Higher Temperature Superconductivity	1.8	1.5	1.5	1.5	2.5	2.5	2.5	2.5	2.5	2.5	17.5	12.5	48.8
TOTAL		24.2	21.8	22.4	22.9	19.9	18.2	17.9	17.9	17.9	74.6	41.4	44.6	343.7
Unassigned		—	—	—	—	2	5	5	5	5	40	70	180	312
TOTAL Including Unassigned		24.2	21.8	22.4	22.9	21.9	23.2	22.9	22.9	22.9	114.6	111.4	224.6	655.7

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE, 1971

TABLE C-III
AC OVERHEAD TRANSMISSION
(Millions of 1971 Dollars)

PRIORITY	PROJECT	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
1	Ultra-High Voltage	2.3	0.8	0.8	1.3	1.3	1.3	1.0	0.8	0.8	2.5	2.5	—	15.4
1	Structures	—	1.0	1.5	2.0	1.8	1.0	0.3	0.3	0.3	1.0	1.0	—	10.2
1	Conductors	—	1.0	2.0	3.0	3.0	2.8	2.0	1.0	0.5	1.3	1.3	—	17.9
1	Insulation	—	1.3	2.0	1.3	1.5	1.0	1.0	0.5	0.3	0.3	1.0	1.0	11.2
1	Electrical Effects	—	1.8	2.3	2.5	1.5	1.0	1.0	0.5	0.5	1.3	0.8	—	13.2
2	R-O-W Capacity	—	—	0.3	0.5	0.3	—	—	—	—	—	—	—	1.1
3	Hardware and Connections	—	0.5	0.8	1.5	1.5	1.5	1.0	0.5	0.5	—	—	—	7.8
3	Tools and Techniques	—	—	0.5	0.5	0.5	0.5	1.0	0.5	0.5	1.0	1.0	—	6.0
4	Grounding and Shielding	—	—	—	—	0.5	0.8	0.8	0.3	—	—	—	—	2.4
TOTAL		2.3	6.4	10.2	12.6	11.9	9.9	8.1	4.4	3.4	7.4	7.6	1.0	85.2
Unassigned		—	—	—	—	—	3	3	7	7	50	50	100	220
Total Including Unassigned		2.3	6.4	10.2	12.6	11.9	12.9	11.1	11.4	10.4	57.4	57.6	101.0	305.2

R&D GOALS TASK FORCE REPORT TO THE
ELECTRIC RESEARCH COUNCIL, JUNE, 1971

TABLE C-IV

DC TRANSMISSION

(Millions of 1971 Dollars)

PRIORITY	PROJECT	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
1	DC Circuit Breaker Development	1.3	1.3	3.0	—	—	—	—	—	—	—	—	—	5.6
1	±600 kV OH Lines	0.8	0.8	—	—	—	—	—	—	—	—	—	—	1.6
1	Mini DC Terminals	1.3	1.3	3.8	3.8	2.5	2.5	2.5	2.5	2.5	—	—	—	22.7
1	Study of Converter System Performance	2.8	2.8	8.9	8.9	—	—	—	—	—	—	—	—	23.4
1	DC Cable	1.3	1.3	0.5	0.5	0.8	0.8	0.8	0.8	1.0	6.3	—	—	14.1
2	Study of Neutral Returns	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.3	—	—	4.0
2	± 750-1500 kV OH Lines	—	—	1.3	2.5	2.0	2.0	2.0	2.0	1.3	—	—	—	13.1
3	HVDC Metering System	—	—	—	0.5	1.0	0.5	—	—	—	—	—	—	2.0
4	DC Transformer	—	—	—	—	—	—	—	—	—	5.0	—	—	5.0
4	Ext. of Term'l Dev. for EHV	—	—	—	—	—	—	—	—	—	12.3	12.3	—	24.6
TOTAL		7.8	7.8	17.8	16.5	6.6	6.1	5.6	5.6	5.1	24.9	12.3	—	116.1
Unassigned		—	—	—	—	10	10	10	10	10	55	70	160	335
TOTAL Including Unassigned		7.8	7.8	17.8	16.5	16.6	16.1	15.6	15.6	15.1	79.9	82.3	160.0	451.1

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE, 1971

TABLE C-V
DISTRIBUTION
(Millions of 1971 Dollars)

PRIORITY	PROJECT	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
1	Installation and Maintenance of Underground Cable Systems	—	0.5	0.8	0.8	0.8	0.8	0.3	0.3	0.3	1.3	1.3	—	7.2
1	Switching and Protective Devices for distribution systems	—	0.8	1.0	1.0	0.8	0.3	0.3	0.8	0.8	3.0	3.0	—	11.8
1	Mini-Substation	—	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.3	1.3	—	6.6
2	Direct Buried Underground Distribution Equipment	—	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.0	2.0	—	8.0
2	Automation of Data Collection and Control of Substation and Field Devices	—	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	2.5	2.5	—	12.0
3	Control of Environmental Factors on Distribution Systems	—	0.3	1.0	1.0	1.0	1.0	0.3	0.3	0.3	1.3	1.3	—	7.8
3	Lightning and Surge Protection	—	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	—	—	2.7
3	Power Transformer Design and Testing	—	—	—	0.5	1.3	1.3	1.3	1.3	1.3	6.3	6.3	—	19.6
4	Customer Transformer and Voltage Control Device	—	—	0.3	0.3	0.3	0.3	0.5	0.5	0.5	1.3	1.3	—	5.3
4	Distribution System Design	—	—	—	—	0.1	0.1	0.1	0.1	0.1	0.8	—	—	1.3
TOTAL			3.4	4.9	5.9	6.6	6.1	5.1	5.6	5.6	20.1	19.0		82.3
Unassigned		—									8	10	55	73
TOTAL Including Unassigned		—	3.4	4.9	5.9	6.6	6.1	5.1	5.6	5.6	28.1	29.0	55.0	155.3

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE, 1971

TABLE C-VI

BULK POWER SUBSTATIONS

(Millions of 1971 Dollars)

PRIORITY	PROJECT	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
1	Circuit Breakers – Increasing Capacity	—	—	—	1.3	1.3	1.3	1.3	1.3	1.3	5.0	—	—	12.8
1	Transformer Materials – Insulation, Core, Conductors	0.3	0.3	0.3	1.0	1.0	0.8	0.8	0.8	0.8	3.0	—	—	9.1
1	Transformer In-Service Monitoring	0.3	0.3	0.3	0.3	0.3	—	—	—	—	—	—	—	1.5
1	Gas Dielectrics	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	—	—	—	—	2.4
2	Fault Detection Methods	—	0.3	0.3	0.3	0.3	0.3	—	—	—	—	—	—	1.5
2	Station Insulating Materials and Contaminants	0.3	0.3	0.5	0.5	0.5	0.5	0.5	0.3	—	—	—	—	3.4
3	Transformer Development-Modular, Short Circuit Test Procedures	—	—	—	1.0	1.0	0.8	0.3	0.3	—	—	—	—	3.4
3	Station Grounding (see also OH Transmission & Distribution)	—	0.3	0.3	0.3	—	—	—	—	—	—	—	—	0.9
4	Station Direct Lightning Stroke Protection	—	—	—	0.3	0.3	—	—	—	—	—	—	—	0.6
4	HV Breakers – Vacuum & Other	—	—	—	—	1.3	2.5	2.5	2.5	2.5	6.3	—	—	17.6
4	EHV Reactor Switching	—	—	—	0.3	0.3	0.3	—	—	—	—	—	—	0.9
TOTAL		1.2	1.8	2.0	5.6	6.6	6.8	5.7	5.5	4.6	14.3			54.1
Unassigned		—	—	—	—	—	8	15	15	15	75	87	175	390
TOTAL Including Unassigned		1.2	1.8	2.0	5.6	6.6	14.8	20.7	20.5	19.6	89.3	87.0	175.0	444.1

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE, 1971

TABLE C-VII
SYSTEM SECURITY AND CONTROL
(Millions of 1971 Dollars)

PRIORITY	PROJECT	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981 1985	1986 1990	1991 2000	TOTAL
1	System Security –On-Line Stability Analysis –Hybrid Analysis of Power Systems –Security Assessment by Stimulation –Systems Equivalents –Optimal Security and Savings –Security Assessment by Probability –State Estimator –Development of Security Criteria	0.8	0.8	1.3	1.3	2.5	2.5	2.5	2.5	2.5	7.5	7.5	5.0	36.7
1	System Stability –Excitation Control –Fast Prime Mover Control –Fast Switching –Modulation of DC –Modulation of Loads –Control from Energy Storage –High Speed Phase Shifter	0.1	0.5	0.5	0.8	1.3	1.3	1.3	0.8	0.8	2.5	2.5	2.5	14.9
2	Intelligence Transmission –Higher Capacity Data Channels –Higher Reliability Data Channels –Higher Reliability Control Channels –High-Speed Control Channels –Effects of Signal Conversion on Control	0.1	0.3	0.5	0.5	0.5	0.5	0.5	0.5	0.3	1.3	1.3	1.3	7.6
2	Control –Local Computer Control –Control Center Computer –Large System Hierarchial Computer –Development of Criteria for Regulating Effort –Performance Criteria for Dynamic Optimization –Modeling and Simulation	0.8	0.8	1.3	1.3	1.3	1.3	1.3	0.8	0.8	2.5	2.5	2.5	17.2
4	Instrumentation –For Plant State Variables –System State Variables –Surge Immunity –Voltage Isolation	0.3	0.3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	2.5	2.5	2.5	13.7
TOTAL		2.1	2.7	4.4	4.7	6.4	6.4	6.4	5.4	5.2	16.3	16.3	13.8	90.1
Unassigned		—	—	—	—	—	—	—	1	1	15	15	50	82
TOTAL Including Unassigned		2.1	2.7	4.4	4.7	6.4	6.4	6.4	6.4	6.2	31.3	31.3	63.8	172.1

R&D GOALS TASK FORCE REPORT TO THE ELECTRIC RESEARCH COUNCIL, JUNE, 1971

APPENDIX D

PART I

CHAPTER 4
ENVIRONMENT
PROJECTED R&D PROGRAM

Appendix D – Part I presents a summary of specific research projects and their estimated costs. Following each task a rank is given; this rank indicates the hierarchical importance of the 71 tasks among themselves. The following correspondence relates the priorities discussed in the main text to these ranks.

Priority	Rank
1	P- 1 through P-14
2	P-15 through P-34
3	P-35 through P-55
4	P-56 through P-71

ELECTRIC POWER INDUSTRY
PROJECTED ENVIRONMENTAL R&D PROGRAM

1 – AIR QUALITY

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
1-1		1.0m/5 yrs	Determine basic physical and chemical data required for sulfur and nitrogen oxide and particulate removal processes.	p-7
1-2		172m/5 yrs	Develop SO_x emission restriction systems for use in existing and future plants.	
	1-2-a	90m/5 yrs	Study of regeneration techniques for sulfur-loaded absorbents, e.g., MgO; Na, K; Ca; others including disposal and elemental sulfur recovery.+	p-1
	1-2-b	82m/5 yrs	Determine relative merits of various gas-liquid contactors including large (full-scale) prototypes.	p-25
1-3		50m/5 yrs	Develop NO_x emission restriction systems which can be used in existing and future plants, includes lower temperature combustion, wet and dry scrubber, boiler modification and additives.+	p-2
1-4		10m/5 yrs	Develop particulate emission restriction system for use in existing and future plants.	
	1-4-a	6.25m/5 yrs	Study of the use of filters and scrubbers to remove extremely fine particulate matter (including any other necessary studies).	p-26
	1-4-b	1.25m/5 yrs	Fundamental study of particulate behavior in electric field, e.g., size, composition, etc.	p-38
	1-4-c	2.5m/5 yrs	Development work including effect of additives and electrode design.	p-51
1-5		30m/5 yrs	Develop feasible process for desulfurizing fuel (coal and oil).	p-14
1-6		7.5m/5 yrs	Continue and intensify efforts to determine health effects (short term - high concentration) of H_2SO_4, SO_x, NO_x and particulates.	

*m indicates millions of 1971 dollars in addition to current government spending.

+ The cost now being incurred by many utilities in the development of various SO_x and NO_x control systems has not been included in the estimates for these tasks.

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
	1-6-a	2.5m/5 yrs	Determine the maximum allowable concentration of each of these and in combination with each other and other emissions such as CO.	p-28
	1-6-b	2.5m/5 yrs	Determine immediate and chronic effects due to single and multiple exposure.	p-64
	1-6-c	2.5m/5 yrs	Determine how these toxicants affect the body.	p-65
1-7		1.5m/5 yrs	Determine effect of major constituents of power plant effluents on vegetation.	p-40
1-8		1.6m/5 yrs	Study of synergistic effects of major stack gas constituents.	
	1-8-a	0.5m/5 yrs	Determine geochemical fate of NO_X, SO_X and particulates in the atmosphere.	p-34
	1-8-b	0.8m/5 yrs	Determine effects of power plant NO_X in combination with particulate matter on smog formation.	p-36
	1-8-c	0.3m/5 yrs	Interaction of SO_X and other pollutants (e.g., kinetics of reactions).	p-37
1-9		5m/5 yrs	Develop standardized portable device to measure low concentrations of SO_X, NO_X and particulates.	p-19
1-10		9m/10 yrs	Participate in the following studies to determine distribution and effects of minor constituents of stack emissions.	
	1-10-a	6.0m/5 yrs	Develop instrumentation and monitoring techniques (in field and at source) for minor elements and compounds (Co, Cu, Fe, Hg, Zn, B, Se, Pb, As).	p-13
	1-10-b	0.5m/5 yrs	Perform laboratory studies to determine, effects of minor stack gas constituents upon plants and animals.	p-16
	1-10-c	0.5m/5 yrs	Determine geochemical fate of minor constituents (cycled - non-cycled).	p-17
	1-10-d	0.5m/5 yrs	Determine the detrimental intake of Cd, B, I, Cr, Se and V caused by local build-up in the body.	p-57
	1-10-e	0.5m/5 yrs	Investigate effects of minor constituents on photosynthesis	p-66

*m indicates millions of 1971 dollars.

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
	1-10-f	0.5m/5 yrs	Evaluate effect of minor constituents of stack gas on plant and animal life.	p-68
	1-10-g	0.5m/5 yrs	Determine new element role in completion of life cycles of organisms.	p-69
1-11		1.1m/5 yrs	Develop dispersion technology.	
	1-11-a	0.2m/5 yrs	Develop quantitative particulate measurement device which can replace Ringelmann standard.	p-24
	1-11-b	0.2m/5 yrs	Determine the interaction of evaporative cooling systems and power plant gaseous emissions.	p-18
	1-11-c	0.5m/5 yrs	Determine correlation between total emissions and ground level concentrations for single and multiple sources.	p-52
	1-11-d	0.2m/5 yrs	Determine the feasibility of advanced aerodynamic techniques for penetration of inversion layers.	p-56
1-12		11.0m/10 yrs	Investigate evaporative cooling system (e.g., cooling tower, spray pond) effects (fogging, icing, etc.).	
	1-12-a	1.5m/5 yrs	Develop improved de-misting system for saline water cooling towers and tower drift loss reduction systems for fresh water cooling towers.	p-4
	1-12-b	1.5m/5 yrs	Determine climatological effects of saline water cooling towers.	p-5
	1-12-c	2m/10 yrs	Develop wind tunnel testing to model cooling tower and spray pond behavior.	p-47
	1-12-d	5.0m/10 yrs	Use field observations and measurements to check validity of models.	p-48
	1-12-e	0.5m/10 yrs	Development of numerical and analytical models.	p-49
	1-12-f	0.5m/5 yrs	Determine what changes in cooling system design will enhance its aesthetics.	p-58
2 – WATER QUALITY				
2-1		5.1m/10 yrs	Investigate effects arising from the disposal of liquid and solid wastes from power plant operation.	

*m indicates millions of 1971 dollars.

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
	2-1-a	5m/10 yrs	Develop adequate disposal techniques for solid wastes from sulfur and nitrogen oxide removal processes.	p-6
	2-1-b	0.1m/2 yrs	Participate in the development of an oil spill containment device which is easily placed around a vessel.	p-55
2-2		8.6m/5 yrs	Determine the effects of once-through cooling systems on aquatic biota.	
	2-2-a	5m/5 yrs	Continue and intensify efforst to determine the effect of thermal plumes on fish, phytoplankton, zooplankton, benthos and marine organisms in the receiving body of water.	p-8
	2-2-b	1.5m/5 yrs	Study the physical and biological (e.g., productivity) effects on fish and on plankton passed through a power plant cooling system.	p-9
	2-2-c	1.5m/5 yrs	Study the design of intake structures and equipment with the purpose of minimizing any deleterious effects which may result from entrainment of fish or exposure to multi-frequency pressure waves.	p-10
	2-2-d	0.25m/5 yrs	Study the effects of a thermal barrier caused by a heated water discharge.	p-50
	2-2-e	0.25m/5 yrs	Develop methods of increasing dissolved oxygen in condenser discharge.	p-61
	2-2-f	0.1m/5 yrs	Evaluate effect of the "thermal bar" observed in large lakes on a thermal plume.	p-67
2-3		4.85m/10 yrs	Develop viable alternate methods of cooling heated water discharges.	
	2-3-a	3m/10 yrs	Develop economic dry cooling tower technology (e.g., corrosion deposition, fluid dynamics, etc.).	p-21
	2-3-b	1.0m/5 yrs	Develop means of comparing dilution rates of submerged vs surface discharge.	p-22
	2-3-c	0.25m/5 yrs	Develop improved hydraulic and heat transfer technology for spray ponds.	p-23
	2-3-d	0.25m/5 yrs	Develop improved hydraulic and heat transfer technology for wet cooling towers utilizing non-utility data.	p-24

*m indicates millions of 1971 dollars.

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
	2-3-e	0.1m/5 yrs	Determine the feasibility of using alternate heat transfer fluids and/or systems.	p-31
	2-3-f	0.25m/5 yrs	Develop computer model for heat and mass transfer between streams of water and between water and air for heated water discharges into all types of receiving water bodies (e.g. river, lake, estuary, etc.).	p-32
2-4		3.0m/20 yrs	Participate in a study to evaluate effects of heated water discharge on the health and aging of aquatic ecosystems.	
	2-4-a	0.75m/20 yrs	Evaluate effects on species diversity and dominant species in selected ecosystems.	p-53
	2-4-b	0.75m/20 yrs	Determine effects of energy transfer within ecosystems.	p-54
	2-4-c	0.75m/20 yrs	Investigate local successional patterns of flora and fauna.	p-59
	2-4-d	0.75m/20 yrs	Study nutrients cycles in different ecosystems – forests, grasslands, streams, and lakes.	p-60
3 – NUCLEAR POWER				
3-1		51.0m/10-20 yrs	Minimize radiation release from nuclear plants.	
	3-1-a	25m/5 yrs	Develop sampling and removal methods for aqueous and gaseous tritium.	p-3
	3-1-b	5m/10 yrs	Develop accidental release removal system capable of at least 99 percent removal of metallic radioiodines and organic radioiodides.	p-11
	3-1-c	1.0m/5 yrs	Improve decontamination efficiencies of liquid rad-waste systems.	p-12
	3-1-d	7.5m/10 yrs	Develop safe removal and long-term disposal storage methods for noncondensibles with long lives (e.g., Kr_{85}).	p-33
	3-1-e	2.5m/10 yrs	Develop instrumentation for continuous radiation measurement very close to background levels.	p-35

*m indicates millions of 1971 dollars.

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
	3-1-f	10m/10-20 yrs	Develop methods for decommissioning nuclear plants.	p-39
3-2		7.5m/5 yrs	Determine cumulative effects of small amounts of radioisotopes on biological systems.	
	3-2-a	1.5m/5 yrs	Determine fate of radionuclides in environment.	p-20
	3-2-b	5m/5 yrs	Evaluate past and on-going studies within the AEC, universities, and independent research organizations in the interest of participating in existing programs.	p-45
	3-2-c	1m/5 yrs	Accumulate available information, assess its scientific validity, and public credibility and repeat general measurements if necessary with the purpose of translating the data into values comparable to reactor-induced radiation for several regions of the U.S.	p-46

4 – GENERAL ENVIRONMENTAL QUALITY

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
4-1		0.4m/10 yrs	Determination of health effect of exposure in electromagnetic fields.	
	4-1-a	0.2m/10 yrs	Determine chronic health effects of long exposure to low intensity fields.	p-62
	4-1-b	0.2m/10 yrs	Determine health effects of short exposure to high intensity fields.	p-63
4-2		0.5m/10 yrs	Develop siting criteria for fossil fuel and nuclear power plants.	p-27
4-3		1.3m/5 yrs	Develop methods of noise control and noise specifications for power plant equipment.	
	4-3-a	0.5m/5 yrs	Develop methods of noise abatement for diesel and gas turbine peaking units.	p-29
	4-3-b	0.35m/5 yrs	Study and develop methods to control noise in existing plants from the following equipment: turbine generators, electric motors, fans, piping systems including valves, pumps and coal mills.	p-30

*m indicates millions of 1971 dollars.

Goal and/or Task No.		Total Funds*	Description of Goal and/or Task	Rank
	4-3-c	0.15m/5 yrs	Develop noise specifications and criteria for locating outdoor plant equipment to have minimal effect on surrounding community.	p-42
	4-3-d	0.15m/5 yrs	Develop criteria for the acoustic room design of power plants for control of in-plant noise for new plants.	p-43
	4-3-e	0.15m/5 yrs	Develop noise specifications for new power plant equipment to include octave band sound power levels and octave band sound pressure levels.	p-44
4-4		1.5m/20 yrs	Develop ecosystem and climatological models to predict long-term effects caused by power generation.	
	4-4-a	0.5m/20 yrs	Develop macro and micro meteorological models to determine effects of CO_2, micro particles and massive heat emissions into the atmosphere caused by electric power generation.	p-41
	4-4-b	0.5m/20 yrs	Perform comparative studies of existing and similar ecosystems with and without power generation facilities.	p-70
	4-4-c	0.5m/20 yrs	Investigate effects of various inputs upon life-energy relationships within trophic levels.	p-71

*m indicates millions of 1971 dollars.

APPENDIX D

PART II

CHAPTER 4
ENVIRONMENT

A major effort involved in any research task is to determine what work has been done up to a given point in time. A research of the literature or a state-of-the-art summary are usually titles given to such investigations. In an attempt to summarize partially what organizations are conducting research in which areas, we have prepared a representative group of listings. The list is keyed to our 22 supporting goals as given in Chapter 4. Thus, Section 1.1 of Appendix D – Part II gives research performed in the general area of air quality related to supporting goal 1.1, "determine basic physical and chemical data related to removal processes for particulates and oxides of sulfur and nitrogen."

The state-of-the-art is very important because knowing where we are allows us to design programs to take us to where we wish to be in an optimum manner. An exact, or near exact, statement of the state-of-the-art for any of our tasks must, by its very nature, be a problem to be solved by specialists in each area. The job is beyond the capabilities of any small group. It will have to be done, however, by those who implement the extensive R&D program we have described in the body of this report.

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Projects determining basic physical and chemical data required for sulfur and nitrogen oxide and particulate removal processes. (1-1)	AEC (Oak Ridge National Laboratory)	Federal Government	Studies of Causes of Comminution of Alkalized Alumina
	American Instrument Company, Inc.	Federal Government	Determination of Surface Area, Pore Volume Distribution and Mercury Density of Limestone and Dolomites
	Battelle Memorial Institute	Federal Government	Kinetics of Sulfur-Oxide Formation in Flames
	Battelle Memorial Institute	Federal Government	Study of Reaction Kinetics of Limestone-Dolomite with Sulfur Dioxide in a Dispersed Solids Contactor
	Bureau of Mines	Federal Government	Mechanisms and Kinetics of Alkalized Alumina
	Bureau of Mines	Federal Government	Regenerative Kinetics of Alkalized Alumina
	Carnegie-Mellon University	Federal Government	SO_2 Sorption by and Removal from Polymeric Materials
	Clarkson College of Technology	Federal Government	Kinetics of Adsorption by Molecular Sieves
	General Technologies Corporation	Federal Government	Infrared Spectroscopic Study of Gas-Solid Interactions
	Illinois Geological Survey	Federal Government	Study of Petrographic and Mineralogical Characteristics of Carbonate Rocks Related to Sulfur Oxide Sorption in Flue Gases
	Lehigh University	Federal Government	Regeneration of Carbon Adsorbents for SO_2

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
	Stanford University	Federal Government	Sulfation Kinetics in SO_2 Absorption from Flue Gas
	Tennessee Valley Authority	Federal Government	Effect of Physical Properties of Limestone, Dolomite, and Their Derivatives on the Kinetics of Reaction with SO_2
	Walden Research Corporation	Federal Government	Standard Chemical Methods for Sampling and Analysis of Gaseous Pollutants from the Combustion of Fossil Fuels
	Walden Research Corporation	Federal Government	Control of Air Pollution from Stationary Fossil-Fuel Combustion Equipment
	West Virginia University	Federal Government	Experimental Investigation of the Penetration and Dispersion Phenomena in the Limestone Injection Method
Projects to develop SO_x emission restriction systems for use in existing and future plants. (1-2)	Abcor, Inc.	–	Aqueous Absorption Systems for SO_2
	AEC (Argonne National Laboratory)	Federal Government	Reduction of Atmospheric Pollution by the Application of Fluidized Bed Combustion
	AEC (Oak Ridge National Laboratory)	Federal Government	Studies of Metal Oxide Absorbers for SO_2 Removal from Stack Gases
	Air Products and Chemicals, Inc.	–	Dry Process for SO_2 Removal
	Aerojet-General	Federal Government	Applicability of Aqueous Solutions for the Development of New Processes for Removing SO_2 from Flue Gases

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Air Preheater Company, Inc.	Federal Government	Evaluation of Potential of Fabric Filters as Chemical Contactors for Control of Sulfur Dioxide from Flue Gas
Allied Chemical Corporation	Federal Government	Applicability of Reduction to Sulfur Techniques to the Development of New Processes for Removing SO_2 from Flue Gas
Atomics International	Federal Government	Development of Molten Carbonate Process for Removal of Sulfur Dioxide from Power Stack Gases
Babcock and Wilcox Company	Commonwealth Edison	SO_2 Removal Through Use Of Venturi Scrubber and Turbulent Contact Scrubber Using Limestone
Babcock and Wilcox Company	Federal Government	Pilot-Plant Investigation to Evaluate the Potential of Direct Limestone-Dolomite Additive Injection for Control of SO_2 from Combustion Flue Gas
Babcock and Wilcox Company	Southern California Edison	SO_2 Removal Through Use of Venturi Scrubber and a Turbulent Contact Scrubber in Series
Babcock and Wilcox Company	Federal Government	Aqueous Slurry Scrubbing of SO_2 from Flue Gases
Babcock and Wilcox Company	—	Magnesium Oxide Scrubbing System and Other SO_2 Removal Processes
Bechtel Corporation	Federal Government	Prototype Study of Limestone Scrubbers for SO_2 Dust Removal Systems
Bureau of Mines	Federal Government	Process Development for Sulfur Dioxide Removal from Flue Gas Alkalized Alumina Process

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Bureau of Mines	Federal Government	Preparation of an Improved Catalyst for Alkalized Alumina
Bureau of Mines	Federal Government	Study of Sorption of SO_2 from Smelter Gases by Alkalized Alumina
Bureau of Mines	Federal Government	Evaluation of Processes for Removal of SO_2 from Flue Gas
Bureau of Mines	Federal Government	Evaluation of Metal Oxides as Sorbents for SO_2 in Power Plant Flue Gases
Callery Chemical Company	Federal Government	Sulfur Recovery from Flue Gas Via Reversible Dry Absorbent
Carnegie-Mellon University	Federal Government	Sulfur Dioxide Sorption by Macroreticular Ion Exchange Resins
The Carborundum Company	–	Limestone Injection with Wet Scrubbing or Bag Filtration
Chemico-Basic	Boston Edison Co. & New England Gas & Electric Association	SO_2 and Wet Scrubbing particulate recovery - MgO
Combustion Engineering, Inc.	Eastern Utilities & Federal Government (NAPCA)	Limestone Injection-Wet Scrubbing Process
Consolidation Coal Company, Inc.	–	Flue Gas Scrubbing, Fluidized Combustion in a Lime Bed
The Detroit Edison Company	–	Wet Scrubbing

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
The Dow Chemical Company	–	Gas-Phase Removal of SO_2 with Solid Alkaline Materials
Esso Research and Engineering Company	Federal Government	Fluidized Bed Contactor for Reaction of SO_2 in Flue Gas with Limestone-Based Material
FMC Corporation	Federal Government	Applicability of Inorganic Solids Other Than Oxides to the Development of New Processes for Removing SO_2 from Flue Gases
General American Transportation Corporation	–	Catalytic Reduction Of SO_2 to Sulfur
General Electric Company	Federal Government	Removal of SO_2 from Flue Gases by Fractional Permeation through Immobilized Liquid Membranes
W. R. Grace and Company	Federal Government	Development of Improved Alkalized Alumina for SO_2 Control
Hydrocarbon Research, Inc.	–	Catalytic Hydrogenation of Fossil Fuels
Illinois Institute of Technology Research Institute	–	Oxidation and Reduction of Catalysts
Kaiser Chemicals	–	Improved Dry Sorbent for SO_2 Removal
M. W. Kellogg	Federal Government	Evaluation of the Alkalized Alumina Process
Mine Safety	Federal Government	Applicability of Inorganic Liquids to the Development of New Processes for Removing Sulfur Dioxide from Flue Gases

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Monsanto Research	Federal Government	Applicability of Catalytic Oxidation to the Development of New Processes for Removing SO_2 from Flue Gases
MSA Research	Federal Government	Applicability of Inorganic Liquids to the Development of New Processes for Removing SO_2 from Flue Gases
Nalco Chemical Company	–	Dry Sorbent for SO_2
National Academy of Engineering	Federal Government	Advisory Service on Scale-Up of Air Pollution Control Processes
North American Rockwell Corp.	Federal Government	Development of Molten Carbonate Process for Removal of Sulfur Dioxide from Power Plant Stack Gases
Owens-Corning Fiberglas Corp.	Federal Government	Evaluation of Fabric Filters to Remove Sulfur Dioxide at Elevated Temperatures
Peabody Coal	Federal Government	Moving Grate Furnace Study of Limestone for Control of Sulfur Oxides
Precipitair Pollution Control, Inc.	Southern California Edison	Gas-Phase Removal of SO_2 with Solid Alkaline Materials and Collection with Fabric Filters
Princeton Chemical Company	Federal Government	Development of Processes to Reduce SO_2 to Elemental Sulfur by Sulfur Reduction
Radian Corporation	Federal Government	Theoretical Description of the Limestone Injection-Wet Scrubbing Process for SO_2 Removal
Research-Cottrell, Inc.	–	Scrubbing Equipment Development

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Reynolds Metals Company	–	Dry Sorbents for SO_2 Removal
Reynolds, Smith and Hills	–	Scrubbing Process for Flue Gas SO_2 Removal
Slick Industrial Company	–	Dry SO_2 Sorbent Development
Stanford Research Institute	Federal Government	Feasibility Study of New SO_2 Control Process Applied to Smelter and Other Low Emission Sources
Stone and Webster	Federal Government	Development of the Stone and Webster – Ionics Sulfur Dioxide Removal and Recovery Process
Tracor, Inc.	Federal Government	Applicability of Metal Oxides to the Develop Development of Processes for Removing SO_2 from Flue Gases
TRW, Inc.	Federal Government	Applicability of Organic Solids to the Development of New Techniques for Removing Oxides of Sulfur from Flue Gas
Tennessee Valley Authority	Federal Government	Pilot Plant Study of Ammonia Scrubbing of Power Plant Stack Gases
Tennessee Valley Authority	Federal Government	Conceptual Design and Economic Evaluation of Process for Reduction of Sulfur Oxide Emissions from Power Generation
Tennessee Valley Authority	Federal Government	Unit Full-Scale Evaluation of Dry Limestone Injection Process for SO_2 Removal from Power Plant Stack Gases

STATE-OF-THE-ART OF ELECTRIC POWER INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Tyco Laboratories, Inc.	Federal Government	Establish the Feasibility of Oxidizing the SO_2 in Power Plant Flue Gases to Sulfuric Acid
Uniroyal, Inc.	Federal Government	The Development of Regenerative Fibers for Removing SO_2 from Flue Gas
United International Research, Inc.	–	Regenerable Scrubbing Process Removal; SO_2 Converted to H_2SO_4
U.S. Stoneware Company	–	Process for SO_2 Control from Sulfuric Acid Plants
Universal Oil Products	Commonwealth Edison	Development of a Two-Stage Sulfoxel Scrubber
Universal Oil Products	–	Dolomite Slurry Scrubbing; Catalytic Hydrogenation of Fuels
Wellman-Lord, Inc.	Tampa Electric Co.; Baltimore Gas & Electric Co., Potomac Electric Power Co.; Delmarva Power & Light Co. and Potomac Edison Co.	R&D of Regenerable Wet Scrubbing Process Plus Direct Reduction of SO_2 to Sulfur
Western Precipitation Group	Joy Manufacturing Co.	Scrubbing Equipment Development
Westinghouse R&D Center	–	Evaluation of the Fluidized Bed Combustion Process
Westvaco	–	Adsorption of SO_2 by Activated Carbon
West Virginia University	Federal Government	Utilization of Pulverized Coal Fly Ash Modified by the Addition of Limestone-Dolomite SO_2 Removal Additives

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
	The Wheelabrator Company	–	Scrubbing Equipment Development
	Wisconsin Electric Power	–	Lime Scrubbing, Other Aqueous Scrubbing Systems
Projects to develop NO_x emission restriction systems which can be used in existing and future plants, includes lower temperature combustion, wet and dry scrubber, boiler modification and additives. (1-3)	AEC (Argonne National Laboratory)	Federal Government	Reduction of Atmospheric Pollution by Application of Fluidized Bed Combustion
	Battelle Memorial Institute	Federal Government	Catalytic Decomposition of NO in Flue Gas
	Bureau of Mines	Federal Government	Flame Characteristics Causing Air Pollution
	Dynamic Science	Southern California Edison	Study of Combustion Phenomena to Further Minimize the Formation of NO_x
	Esso Research and Engineering Company	Federal Government	System Study of Nitrogen Oxides Control Methods for Stationary Sources
	Massachusetts Institute of Technology	Federal Government	Model for NO Formation in the Combustion Process
	Southern California Edison	–	Off-Stoichiometric Combustion to Effect NO_x Reduction
	University of California, Berkeley	–	Catalytic Reduction of Oxides of Nitrogen
	University of Colorado	–	Catalytic Mechanisms for Nitrogen Oxides Reduction
	University of Massachusetts	Federal Government	SO_2 and NO_2 Removals from Stack Gases by CO

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Projects to develop particulate emission restriction system for use in existing and future plants. (1-4)	Belco Industrial Equipment Co.	Federal Government	Pulsed Power Supply for Electrostatic Precipitators
	GCA	Federal Government	Fabric Filter System Study
	McCrone Associates, Inc., Walter C.	Federal Government	Standard Manual Methods for Particulate Measurements for Fossil-Fuel Combustion Sources
	Midwest Research Institute	Federal Government	Particulate Pollutant System Study
	Research Cottrell	Federal Government	Particulate Collection Study – TVA Dry Limestone Tests
	Southern Research Institute	Federal Government	Electrostatic Precipitator Systems Study
	University of Illinois	–	Boundary Layer Flow in Electrostatic Precipitators
Projects to develop feasible process for desulfurizing fuel (coal and oil). (1-5)	Battelle Memorial Institute	Federal Government	Fuel Availability-Cost Model Study
	Bituminous Coal Research	Federal Government	An Evaluation of Coal Cleaning Methods and Techniques for Removal of Pyritic Sulfur from Fine Coal
	Black, Sivalls, & Bryson, Inc.	–	Coal Gasification in Molten Iron; Sulfur Removal in Slag
	Bureau of Mines	Federal Government	Characteristics and Removal of Pyritic Sulfur from American Coals
	Bureau of Mines	Federal Government	Removal of Pyrite Coal in a Humphrey Spiral of Conventional and Modified Design
	Bureau of Mines	Federal Government	Removal of Pyrite Coal by Tabling

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
	City College Research Foundation	Federal Government	Desulfurization of Fuels by Calcined Dolomite
	Consolidation Coal Company, Inc.	–	Pyrite Removal from Coal
	General Technologies Corp.	Federal Government	Solvent-Refined Coal Cost Study
	Institute of Gas Technology	–	Coal Gasification
	Scientific Research Instruments Corp.	Federal Government	Studies of Sulfur Control Using Coal Gasification
	United Aircraft	Federal Government	Technological and Economic Feasibility Study of Advanced Power Cycles and Methods of Producing Non-Polluting Fuels
	University of Illinois	Federal Government	Sampling and Evaluation of Coal Mines In Illinois by the Illinois Geological Survey
Projects to determine health effects (short-term – high concentration) of H_2SO_4, SO_x, NO_x and particulates. (1-6)	Hazleton Laboratory	EEI	Health Effects Due to Exposure to SO_2, H_2SO_4, and Particulates and Mixture
	NAPCA (Division of Health Effects Research)	Federal Government	Effects of Community Exposure to Nitrogen Dioxide
Projects to determine effect of major constituents of power plant effluents on vegetation. (1-7)	Air Pollution Research Center; University of California	–	Effects of Photo-chemical Oxidants on Vegetation in Urban and Surrounding Areas
	The Detroit Edison Company	–	Effect of SO_2 on Vegetation in Area Surrounding Monroe Power Plant Site

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
	Kennecott Copper Corp.	–	Evaluation of Sulfur Dioxide Injury to Economic Crops
	Tennessee Valley Authority	Federal Government	Effect of Steam Plant Operation on the Appearance and Growth of Timber Stands
Projects studying synergistic effects and interaction of NO_x, SO_x and particulates. (1-8)	Tennessee Valley Authority	Federal Government (NAPCA)	Atmospheric Dispersion and Interaction of SO_2, H_2SO_4, NO_x, O_3 and Particulates in Stack Emissions from Coal-Fired Power Plants
	University of Massachusetts	Federal Government	SO_2 and NO_2 Removal from Stack Gases by by CO
Projects to develop measurement device for low concentrations of major stack gas constituents. (1-9)	Walden Research Corporation	Federal Government	Standard Chemical Methods for Sampling and Analysis of Gaseous Pollutants from the Combustion of Fossil Fuels
	Walter C. McCrone Associates	Federal Government	Standard Manual Methods for Particulate Measurements for Fossil Fuel Combustion Sources
	(Contractor not selected)	Federal Government	Continuous Particulate Monitors for Fossil Fuel Combustion Sources
Projects to determine distribution and effects of minor constituents. (1-10)	AEC (Agricultural Research Lab)	Federal Government	Study Factors Influencing Absorption and Excretion and Effects of Iodine
	Cornell University	Federal Government	Influence of Iodine Intake on Kinetics of Iodine Metabolism in the Dog
	Louisiana State University	Federal Government	Selenium and Its Significance as an Air Pollutant

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Projects to develop dispersion technology. (1-11)	EEI	–	Development of Scientifically Acceptable Techniques and/or Instrumentation for Measuring Stack Plume Opacity
	EEI	–	Dispersion Characteristics of Stack Effluents, Effluents, Development of a Formula for Stack Design
Projects to determine evaporative cooling system effects. (1-12)	The Detroit Edison Company	–	Environmental Effects of Spray Ponds
	FWQA (EC&G Incorporated)	Federal Government	Theoretical Evaluation and Development of a Criteria to Determine Inadvertent Weather Modification in the Vicinity of Cooling Towers
	Tennessee Valley Authority	Federal Government	Environmental Effects of Cooling Tower Plumes
Projects to investigate effects arising from disposal of liquid and solid waste from power plant operation. (2-1)	(Most of the projects to develop SO_X and NO_X restriction systems (1-2 and 1-3) have as a goal the development of adequate disposal techniques for the solid or liquid wastes, thereby minimizing the effects of these systems. It would be repetitious to present the list again in this section.)		
	Johns-Manville	Federal Government	Development of Oil Containment Device
Projects to determine effects of once-through cooling system on aquatic biota. (2-2 and 2-4)	AEC	Federal Government	Study of the Effects of Waste Heat Release
	Academy of Natural Sciences	Baltimore Gas & Electric Company	Pre-Operational Aquatic Studies at Calvert Cliffs Nuclear Power Plant

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Commonwealth of Massachusetts	Boston Edison Co.	Survey-Study Program to Determine Life Stages and Distribution of Important Fish Species and Their Ability to Avoid, Survive or Benefit From Warm Discharge Waters, the Currents Generated by Plant Operation and the Fish Screens at the Intake Structure
FWQA (Pacific Northwest Water Laboratory)	Federal Government	Coordination of Various Thermal Pollution Programs to Determine Effects of Temperature Changes on Water Uses
FWQA (Institute of Marine Sciences, University of Miami)	Federal Government	Determine Effect of Thermal Effluent on Micro Fauna and Flora of Biscayne Bay
Institute of Water Research (Michigan State University)	The Detroit Edison Company	Ecological Survey Conducted Prior to and During Operation of Monroe Power Plant
Johns Hopkins University	EEI	Determine Thermal Effects on Plant and Animal Life in Rivers, Lakes and Marine Water Bodies
Northwestern University	Commonwealth Edison Company	Study to Determine Any Long-Term Deleterious Effect on the Aquatic Life Due to Thermal Discharge
Southern California Edison	—	Effects of Thermal Discharge at San Onofre on Marine Ecology
Woods Hole Oceanographic Institute	Boston Edison Co.	Prediction of Ecological Effects of Heated Water Discharge

(Read "Heated Effluents and Effects on Aquatic Life with Emphasis on Fishes," 11* a bibliography of 1870 references and "A Summary of Environmental Studies on Water Problems."8)

*Number refers to number of citation in bibliography.

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
Projects to develop viable alternatives for cooling heated water discharge. (2-3)	AEC	Federal Government	Engineering Evaluation of Improved Methods of Waste Heat Dissipation
	FWQA (Dynatech Corp.)	Federal Government	Survey and Economic Analysis of Alternate Methods for Cooling Condenser Discharge Water
	FWQA (Littleton Research and Engineering Corp.)	Federal Government	Program to Provide In-Depth Information on Cooling Pond Behavior
	FWQA (Pacific Northwest Water Laboratory)	Federal Government	Program to Evaluate Design, Cost, Efficiencies, Advantages and Disadvantages of Various Treatment Method of Cooling Heated Water; Also Applicability of Non-Treatment Methods of Control Such as Improved Power Plant Efficiencies Will Be Evaluated
	Virginia Electric & Power Co.	—	Evaluation of Spray Ponds
	The Detroit Edison Company	—	Evaluation of Spray Ponds
Projects to minimize radiation release from nuclear plants. (3-1)	AEC (Oak Ridge National Laboratory)	Federal Government	Effects of Filter Operational Efficiency in a Post-Laboratory Environment
	AEC (Oak Ridge National Laboratory)	Federal Government	Use of Water Sprays with Chemical Additions to Remove Air-Borne Fission Products
	AEC (Pacific Northwest Laboratory	Federal Government	Spray Systems Using Simulated Fission Products

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
	Battelle Memorial Institute	Federal Government	Program to Develop Practical Containment Surface Coatings Which Would Retain Significant Fractions of Accident-Released Fission Products
Projects to determine cumulative effects of small amounts of radio-isotopes on biological systems. (3-2)	AEC (Oak Ridge Associated Universities)	Federal Government	Study of Effects and Responses of Patients to Low Exposure Rates of Radiation
	(Read pages 44-162 of "Summaries of USAEC Environmental Research and Development"[19]* for projects to determine effects of radioisotopes on biological systems.)		
Projects to determine health effects of exposure in electromagnetic fields. (4-1)	(Read "Biological Effects of Magnetic Fields"[20] for a synthesis of research in this area prior to 1964 and "Biological Effects and Health Implications of Microwave Radiation"[21] for an up-to-date "state-of-the-art" in this area.)		
Projects to develop methods of noise control for power plant equipment. (4-3)	AEC	Federal Government	Reactor Siting and the Environment, a coordinated program to obtain quantitative data in the areas of hydrology, geology, seismology, meteorology,and other factors affecting or affected by the siting operation of nuclear power plants.
	Tennessee Valley Authority	Federal Government	Siting Criteria for Power Plants
	The Detroit Edison Company	--	Study Effectiveness of Techniques for Acoustical Treatment of Piping System to Reduce Fluid Flow Noise Radiating from the Pipe

*Number refers to number of citation in bibliography.

STATE-OF-THE-ART OF ELECTRIC UTILITIES INDUSTRY-RELATED ENVIRONMENTAL RESEARCH (Continued)

	RESEARCH ORGANIZATION	SPONSOR	PROJECTS
	The Detroit Edison Company	—	Study Techniques to Reduce Noise from Pneumatic Tools
	Department of Defense	Federal Government	Study of Occupational Noise Problems
	Fisher Valve	—	Valve Noise Abatement
	HEW	Federal Government	Determine Effect of Noise on Hearing
	Kopper Company Inc.	Florida Power Copr.	Methods of Control of Turbine and Plant Noise
	Industrial Acoustics Co.	The Detroit Edison	Design of Exhaust Silencer for Diesel Peaking Unit
	National Bureau of Standards	Federal Government	Study of Environmental Noise and the Development of a Mobile Noise Laboratory
	Otter Tail Power Company	—	Noise Abatement on Coal Car Shakers
	Stone and Webster	Duquesne Light Co.	Power Plant Noise Control at Cheswick Power Plant
Projects to develop ecosystem and climatological models. (4-4)	Budyko	USSR	Global Climatological Models Incorporating the Incoming and Outgoing Solar Radiation and the Albedo
	Milankovitch	—	Mathematical Climatological Model Incorporating Time Variations of the Earth's Position in Space with Respect to the Sun
	Manabe, S. and Wetherald, R.T.	—	Climatological Model Relating CO_2 Increase to Temperature Rise

APPENDIX D

PART III

BIBLIOGRAPHY FOR CHAPTER 4
ENVIRONMENT

AIR QUALITY

1. "Abatement of Sulfur Oxide Emissions from Stationary Combustion Sources," Engineering National Research Council, 1970.
2. "A History of Southern California Edison Company Research and Development on Protecting the Quality of the Environment," Southern California Edison, 1970.
3. "Air Pollution and the Regulated Electric Power and Natural Gas Industries," FPC, September 1968.
4. "Air Pollution – 1970," Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate, pp. 353-359, March 1970.
5. "Impact of Air Pollution on Vegetation," Conference Proceedings, APCA (Ontario), April 1970.
6. "Research and Development for Control of Air Pollution from Stationary Sources," HEW (NAPCA), September 1969.
7. "Sulfur Oxides Pollution Control, Federal Research and Development, Planning and Programming 1968-1972," HEW, April 1968.

WATER QUALITY

8. "A Summary of Environmental Studies on Water Problems by Investor-Owned Electric Utility Companies Recently Completed, Underway and Proposed," Edison Electric Institute, June 1969.
9. Bloom, S.C., "Heat–A Growing Water Pollution Problem," *Environmental Reporter:* Vol. 1, No. 1, pp. 1-21, May 1, 1970.
10. Parker, F.L. and Krenkel, P.A., "Thermal Pollution: Status of the Art," Department of Environmental and Water Resources Engineering, Vanderbilt University, December 1969.
11. Raney, E.C. and Menzel, B.W., "Heated Effluents and Effects on Aquatic Life with Emphasis on Fishes," April 1969.

12. "Water Pollution–1970," Subcommittee on Air and Water Pollution of the Committee on Public Works, United States Senate Hearings, pp. 777-876, May 1970.

NUCLEAR POWER

13. "AEC Authorizing Legislation Fiscal Year 1971," Joint Committee on Atomic Energy Hearings, March 1970.
14. "Annual Report to Congress of the Atomic Energy Commission for 1969," January 1970.
15. "Fundamental Nuclear Energy Research, 1968," January 1969.
16. "Fundamental Nuclear Energy Research, 1969," January 1970.
17. "Major Activities in the Atomic Energy Programs, January-December 1969," USAEC, January 1970.
18. "Radionuclides in the Environment," American Chemical Society Symposium Proceedings, April 1968.
19. "Summaries of USAEC Environmental Research and Development," USAEC, September 1970.

GENERAL ENVIRONMENTAL QUALITY

20. Barnothy, M.F., "Biological Effects of Magnetic Fields," Plenum Press, New York, 1964.
21. "Biological Effects and Health Implications of Microwave Radiation," Symposium Proceedings, U.S. Department of HEW, June 1970.
22. Budyko, M.I., Sov. Geog'r: Rev. Transl. 10, 429 (1969) *Journal of Applied Meterology*, 9, 310 (1970).
23. Cambel, A.B., et al, "Energy R&D and National Progress," U.S. Government Printing Office, Washington, D.C., 1965.
24. "Cleaning our Environment–The Chemical Basis for Action," American Chemical Society, 1969.
25. "Electric Power and the Environment," Office of Science and Technology, August 1970.
26. Manabe, S. and Wetherald, R.T., *J. Atmos. Sci.* 24, 241 (1967).
27. Milan Kovitch, M., "Canon of Isolation and the Ice Age Problem," Translation of *Kgl. Servische Akad.*, Spec. Publ. 132 (1941) by Israel Program Sci. Transl. (1969) U.S. Department Comm. Clearing House Fed. Sci. Tech. Inform.
28. "Noise from Power Plant Equipment," The Institution of Mechanical Engineers Symposium Proceedings, September 1966.
29. "Noise, Sound Without Value," Committee on Environmental Quality of the Federal Council for Science and Technology, September 1968.
30. Winzer, G.E., "National Bureau of Standards Mobile Acoustical Laboratory," *Sound and Vibration*, p. 12, May 1970.

APPENDIX E

CHAPTER 5
UTILIZATION

OPPORTUNITY AREAS FOR R&D IN UTILIZATION OF ENERGY BY THE CONSUMER

Six basic categories of investigation have been identified for R&D in consumer utilization. These categories cover the selected areas of opportunity for coordinated research and development concerned with the utilization of electric energy by the consumer which must be fully supported by the electric utility industry, manufacturers, government and others.

These six categories have been further subdivided into thirteen distinct opportunity areas. These thirteen areas, shown in summary below, are then individually described on the following pages.

	PRIORITY	FUNDING (millions of 1971 dollars)
I. Environmental – covering those electric energy R&D activities related to the condition and improvement of man's natural and social surroundings (consumer applications).		
A. Natural Environment		
1. Waste heat utilization	1	$ 27.0
2. Air pollution controls	1	8.3
3. Water and sewage treatment	1	32.0
a. domestic and industrial		
b. river and lakes clean-up		
c. solid waste management		
B. Social Environment		
1. Standard of living	2	1.8
2. Noise control	3	2.4
3. Leisure time	4	4.6
II. Transportation – covering those electric energy R&D activities related to the condition and improvement of the movement of humans and the products and goods of industry and commerce.		

	PRIORITY	FUNDING (millions of 1971 dollars)
A. Materials Transportation	1	$ 5.0
B. Mass Transportation	1	54.0
C. Personal Transportation	1	118.0
III. Agricultural – covering those electrical energy R&D activities related to the condition and improvement of food, fiber, and forestry products or their synthetic substitutions.		
A. Production) B. Processing) C. Storage)	3	7.8
IV. Manufacturing – covering those electric energy R&D activities related to the condition and improvement of manufacturing technology.		
A. Systems to Replace Polluting Systems) B. Systems to Increase Productivity)	1	7.8
V. Increase efficiency of consumer devices in Home and Commerce – covering those electric energy R&D activities related to the condition and improvement of methods used in the creation of residential and nonresidential structures and functions within.		
A. Structrual Systems and Components) B. Systems and Appliances) C. Lighting Systems) D. Environmental Systems)	1	59.0
VI. Communications – covering those electric energy R&D activities related to the condition and improvement of information gathering, processing, transmitting, and utilization.		
A. Communications) 1. Personal) 2. Business) B. Education)	3	5.4
SUM OF FUNDING REQUIREMENTS FOR ALL OPPORTUNITY AREAS		333.1
Unassigned		36
Total Including Unassigned		369

OPPORTUNITY AREA: I-A-1

TITLE: Utilization of Low Grade Thermal Energy (Waste Heat)

DESCRIPTION:
Determine uses of low grade discharge heat from power plants through studies and demonstration projects.

BENEFITS AND GOALS:
The quantity of heat which must be dissipated to the environment by a steam generation plant is substantially larger than the quantity of heat that is converted to electricity. The goal of this program would be to turn this previously wasted low grade thermal energy into a resource. The application of low grade heat for urban systems, aquaculture and agriculture may provide social and/or economic benefits.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$27 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.5	1.0	1.0	1.0	1.0	1.0

OPPORTUNITY AREA: I-A-2

TITLE: Air Pollution Controls (consumer applications)

DESCRIPTION:

The combustion and processing of fossil fuels and the discharge of fumes and particulates into the atmosphere pose a serious problem. The project will be to minimize air contamination from polluting sources of the consumer through the implementation of new methods of filtration or to develop a pollution-free replacement for the contaminating process.

BENEFITS AND GOALS:

Present day smog and pollution already pose a serious threat to the health of human beings and vegetation. Research to develop high efficiency filters, scrubbers, collectors, electrostatic and ultrasonic devices for precipitating pollutants are a high priority. By acquiring the knowledge for the control of air pollution through research and development, man will be able to continue his way of life. The possibility of eliminating automobile exhaust pollutants will be discussed under the project on transportation.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$8.3 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 2000
0.2	0.5	0.5	0.5	–

OPPORTUNITY AREA: I-A-3

TITLE: Water Reclamation, Sewerage and Solid Waste Management

DESCRIPTION:
Revise, test and develop applications of electric energy to improve domestic and industrial water processing, river and lake clean-up, and solid waste management.

BENEFITS AND GOALS:
Improve our current abilities to meet the requirements for domestic and industrial water in urban areas and on an individual unit basis. Meet the requirements for improved treatment of sewage and solid wastes in urban areas and on an individual unit basis. Improve the quality of our rivers and lakes.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$32 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1985	1996 to 2000
0.5	1.5	1.5	1.0	1.0	1.0

OPPORTUNITY AREA: I-B-1

TITLE: Standard of Living

DESCRIPTION:
Identify, test, and correlate the standard of living with energy usage.

BENEFITS AND GOALS:
The relationship of growth and socio-economic progress to energy usage, and more particularly electric energy, needs to be identified.

PRIORITY RATING OF OPPORTUNITY AREA: *2*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$1.8 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.03	0.1	0.06	0.06	0.06	0.06

OPPORTUNITY AREA: I-B-2

TITLE: Noise Control

DESCRIPTION:
Identify, measure and evaluate each major contributor to the ambient noise level within all classes of residential, commercial and industrial occupancies.

BENEFITS AND GOALS:
This basic research will allow us to dedicate our efforts towards minimizing the concern over noise pollution from electro-mechanical equipment and will enhance the acceptance and satisfaction by the nation's appliance and equipment users.

PRIORITY RATING OF OPPORTUNITY AREA: *3*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$2.4 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 2000
0.1	0.2	0.2	–

OPPORTUNITY AREA: I-B-3

TITLE: Leisure Time Activities

DESCRIPTION:

Identify and develop task saving and recreational functions in and about the home which lend themselves to the field of electrification. Identify, research, and develop opportunities in the electrification of leisure functions away from home.

BENEFITS AND GOALS:

The development of electric residential task saving and leisure time equipment will enhance the ecology through the ultimate reduction of noise, air, and water pollution, and provide man with the desired outlet for his expanding leisure time activities.

PRIORITY RATING OF OPPORTUNITY AREA: *4*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$4.6 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.03	0.1	0.2	0.2	0.2	0.2

OPPORTUNITY AREA II-A

TITLE: Materials Transportation

DESCRIPTION:
Study, develop, and test modes of material transportation and special service vehicles.

BENEFITS AND GOALS:
To intensify the application of electric energy to in-plant vehicles such as fork-lift, pallet, reach, and platform trucks, food service carts, tractors, personnel carriers, and to special service and in-street vehicles.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$5 Million*

ANNUAL EXPENDITURE
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.05	0.15	0.2	0.2	0.2	0.2

OPPORTUNITY AREA: II-B

TITLE: Mass Transportation

DESCRIPTION:
Study, develop, and test applications of electric energy relative to the movement of humans, products and goods by rapid transit and electrification of railroads by current methods and others, such as the linear induction motor.

BENEFITS AND GOALS:
Mass transportation is an important link in a well-balanced transportation system, developed with judicious planning of land use. Electrified public transportation can be made comfortable, clean, quiet, safe, fast, dependable, and convenient. This program envisions participation in selected demonstrations.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$54 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
1.0	3.0	3.0	2.0	1.0	1.0

OPPORTUNITY AREA: II-C

TITLE: Personal Transportation

DESCRIPTION:

Design and develop marketable electric personal transportation through improved transportable power source.

BENEFITS AND GOALS:

Reduce vehicular emission pollution by the substitution of electric vehicles. Nuclear-age electric power resources will free remaining fossil fuels for other uses, such as chemical content.

A primary objective will be the development of a higher energy-density transportable power source. Specifically this program envisions the doubling of the energy-density capability of existing battery systems by 1975; 80-100 Wh/pound systems by 1980; and 150-200 Wh/pound systems by 1990.

The development of the higher energy-density transportable power source will add significant impetus to industry for extending the benefits of this new power source to other opportunity areas.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$118 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
4.5	6.0	3.0	5.0	4.0	2.0

OPPORTUNITY AREA: III-A, B & C

TITLE: Agriculture

DESCRIPTION:
Basic research and development of new methods of food production, processing, storage, preservation, and distribution utilizing electrical energy.

BENEFITS AND GOALS:
Advanced techniques in food production and processing could ultimately increase food value and vitamin content, reduce crop losses and spoilage to enable a more efficient production of a palatable product. The ultimate result would provide food supplies to meet the demands of the expanding world population and increase the effective production level of crop lands.

PRIORITY RATING OF OPPORTUNITY AREA: *2*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$7.8 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.2	0.2	0.3	0.3	0.3	0.3

OPPORTUNITY AREA: IV-A & B

TITLE: Manufacturing

DESCRIPTION:

Develop, test, and relate the use of electric energy to the condition and improvement of manufacturing technology.

BENEFITS AND GOALS:

Commerce and industry will benefit from improved quality control and process flexibility enabling them to produce greater quantities of an improved product. The net result will be to increase productivity, reduce pollution contributing processes and conserve fossil fuel energy.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$ 7.8 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.2	0.2	0.3	0.3	0.3	0.3

OPPORTUNITY AREA: V-A, B, C, D

TITLE: Efficient Use of Energy in Home and Commerce

DESCRIPTION:

Optimize the efficiency of heating, cooling, lighting and ventilating sources and devices. Test and develop the optimum relationship of the flow of energy to and from conditioned spaces; i.e., heating, cooling, lighting, and related functions within residential and non-residential structures.

BENEFITS AND GOALS:

Home and commerce are to be provided a greater selection of light sources with high efficiency, long life, and heat recovery to meet the expanding requirements in the conservation of energy. The development and application of new materials and new methods of producing synthetic materials to control the flow of energy will reduce the required space conditioning equipment size and energy consumption, and will enable us to provide a more comfortable environment for man while accomplishing our goal of energy conservation. Not only can the enclosed controlled environment become a more healthful one, but will also extend into numerous other benefits of a psychological nature; such as, higher student achievement levels in schools, employee morale, and on-the-job efficiency.

PRIORITY RATING OF OPPORTUNITY AREA: *1*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$59 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
1.0	2.0	3.0	2.0	2.0	2.0

OPPORTUNITY AREA: VI-A & B

TITLE: Communications

DESCRIPTION:
Develop and identify improved communication modes based on the use of electrical energy.

BENEFITS AND GOALS:
Improved communication technology will provide the opportunity for the user to vastly expand his capacity to interact and react within his environment. We must keep pace with and improve information gathering, processing, transmitting and utilization.

PRIORITY RATING OF OPPORTUNITY AREA: *3*

COMMITMENT DEDICATED TO THIS OPPORTUNITY AREA: *$5.4 Million*

ANNUAL EXPENDITURES
(millions of 1971 dollars)

1972 to 1975	1976 to 1980	1981 to 1985	1986 to 1990	1991 to 1995	1996 to 2000
0.1	0.2	0.2	0.2	0.2	0.2

APPENDIX F

PART I

CHAPTER 6 – INDUSTRY GROWTH AND SYSTEM DEVELOPMENT

ENERGY REQUIREMENTS

TOTAL ENERGY REQUIREMENTS

Population Growth

During the thirty-year interval between 1970 and 2000, the U.S. Bureau of Census estimates the population of the United States will increase by 75,573,000 or 36.8 per cent based on projected fertility rates and mortality and immigration rates.[6]

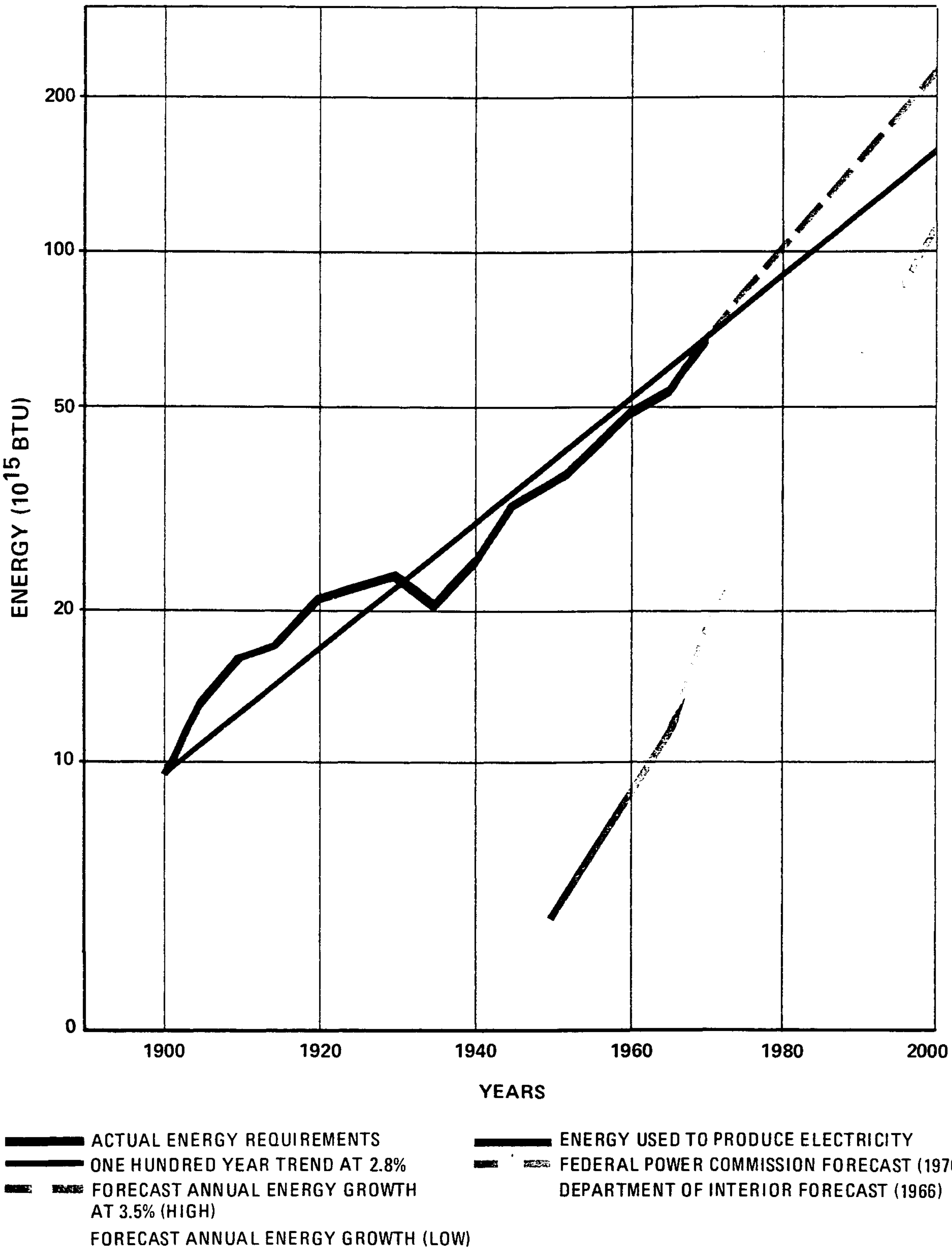
	1970		1980		1990		2000
Population (Thousands)	205,167		227,510		254,720		280,740
Incremental Increase (Thousands)		22,343		27,210		26,020	
Per cent Increase		10.9		11.96		10.2	

However, other projections indicate population levels from 266,281,000 to 320,780,000 in the year 2000 without a leveling off in the rate of growth.

User Energy Requirements

In 1850, the population of the United States was about 23 million – at the last census, the population was in excess of 205 million – an increase of almost nine times. During this same interval, the total energy requirements increased almost 30 times. During this period in which the basic economy of the United States shifted from agriculture to industry, the comparative growth in energy requirements was less than that predicted for the next 30 years. By the year 2000, the 36.8 per cent growth in population is accompanied by energy increase of 250 per cent (Figure F-1) a rate of growth twice that experienced in the past. While coal still provides 45 per cent of the energy supply, the three fossil fuels – coal, oil, and gas – cannot maintain that dominant role in the future. Table F-I shows the total energy consumption by fuel and consuming sector in the United States. (Gross National Product (GNP) annual growth rate of 4 per cent has been assumed.)[7]

HISTORIC AND FORECAST TOTAL
U. S. ENERGY REQUIREMENTS



R & D Goals Task Force Report to the Electric Research Council, June, 1971

FIGURE F-1

Table F-I
TOTAL ENERGY CONSUMPTION FORECAST BY FUEL AND CONSUMING SECTOR
(trillions of BTU's)

Forecast tabulations:	**1970**	**1975**	**1980**	**2000**
Household & Commercial:				
(Used as direct fuels)				
Gas	*7,350*	*8,485*	*10,000*	*19,066*
Petroleum	*5,979*	*6,512*	*6,940*	*2,000*
Coal	*508*	*454*	*325*	
Total	**13,837**	**15,451**	**17,265**	**21,066**
Industrial:				
Gas	*8,988*	*10,458*	*11,780*	*17,504*
Petroleum	*5,481*	*6,431*	*7,104*	*13,090*
Coal	*5,901*	*5,557*	*5,749*	*2,000*
Total	**20,370**	**22,446**	**24,633**	**32,594**
Transportation:				
Gas	*560*	*628*	*698*	*1,000*
Petroleum	*14,959*	*18,069*	*20,736*	*41,649*
Coal	--	--	--	--
Total	**15,552**	**18,697**	**21,434**	**42,649**
Electric Utilities:				
Gas	*2,589*	*2,789*	*2,976*	*4,128*
Petroleum	*856*	*863*	*861*	*861*
Coal	*8,035*	*11,134*	*12,516*	*18,720*
Hydro	*2,193*	*2,422*	*3,027*	*5,056*
Nuclear	*874*	*1,803*	*4,878*	*43,526*
Total	**14,547**	**19,011**	**24,259**	**72,291**
Miscellaneous:				
Gas	—	—	*337*	—
Petroleum	—	—	—	—
Coal	—	—	*147*	—
Total	—	—	**484**	—
Total Gross Consumption	**64,276**	**75,605**	**88,075**	**168,000**

From: U.S. Dept. of Interior Projection, "An Energy Model for the United States Featuring Energy Balances for the years." IC8384, July 1968

The long-range forecast of energy production in the U.S. indicates an annual growth rate of nearly 3.5 per cent. Some scientists believe this growth will require at some future date the establishment of a ceiling on energy production. When energy is produced, converted or used, heat is a by-product. This heat must be absorbed by the earth and its surrounding atmosphere and there may be a limit to the amount of man-made waste heat which can be tolerated.

ELECTRIC LOAD FORECASTING

LOAD GROWTH

The proportion of the U.S. total energy supply being used to generate electricity is steadily increasing. Growth in electrical energy has for many years been twice the rate of growth of total energy. The proportion of energy used for production of electricity has increased from 11 per cent in 1920 to over 20 per cent in 1960, and it is estimated by the Federal Power Commission to exceed 30 per cent by 1980.

Forecasts of future power requirements are sensitive to factors such as technological developments, marketing activities, and the attitude of the public toward environmental and ecological problems.

Two projections of electric power system demands to year 2000 are attached (Figure F-2). The curves are based on forecast data to year 1990 issued by FPC late in 1969, and data to year 2000 issued by *Electrical World,* July 6, 1970. Extrapolation of the FPC data to the year 2000 was made on the basis of an analysis of the trend of incremental growth rates. The curve indicates a non-coincidental peak demand for the contiguous U.S. in the year 2000 of 1950 gigawatts (a gigawatt equals 1,000,000 kilowatts). Non-coincidental peak demand for year 2000 in the *Electrical World* projection was approximately 1560 gigawatts.

Estimates of electrical energy consumption by major categories for the same period appear in the tabulation (Table F-II). It is estimated by year 2000 the total energy requirements for the nation will reach 8.9 to 10.4 trillion kilowatt hours depending upon the projection used.

While the proportionate use of the electrical energy by the three major categories (residential, commercial, industrial) does not change appreciably in the next 30 years, based on a 36.8 per cent growth in population, the projected residential electrical energy use will increase 506 to 647 per cent based on either the *Electrical World* or FPC projection. On a per capita basis this becomes about 1860 kWhr for 1970 compared to a projected 8800 kWhr for year 2000.

LOAD CHARACTERISTICS

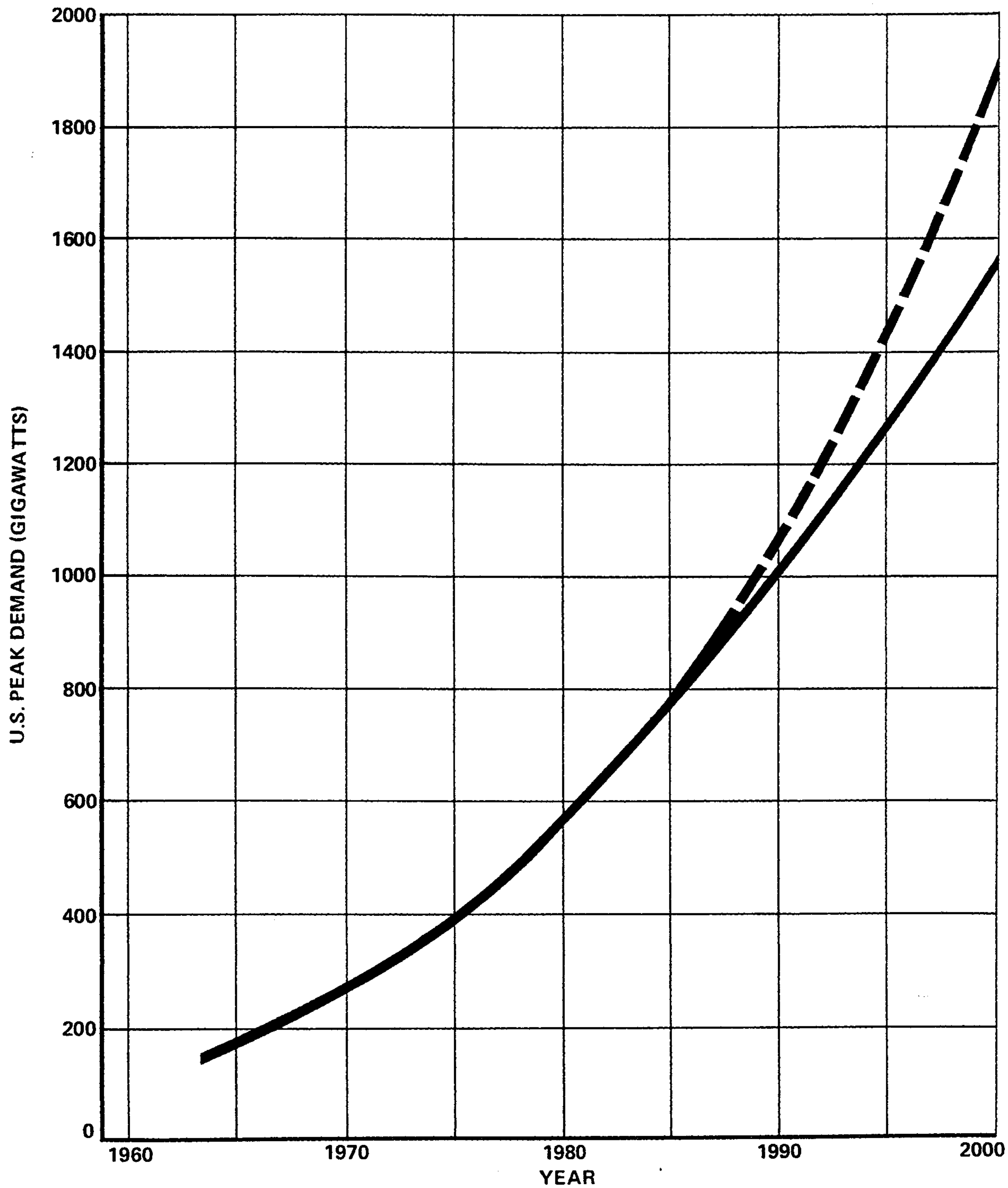
Density

Load density forecasts have been made for the greater part of the United States for 1970 and 1980. These forecasts appear in NERC-TAC Task Force Report on Interregional Coordination issued by the National Electric Reliability Council. For 1970 peak-load density for large regions of the country ranges from a high of 0.535 MW/sq. mile to a low of 0.026 MW/sq. mile. In 1970 the projected load densities increase to a high of 1.220 MW/sq. mile and a low of 0.05 MW/sq. mile.[4] As could be expected the greatest peak-load density appears in the eastern and northeastern central regions. Within a region a load-density pattern is subject to wide variations; for example, Manhattan with a high of 165 MW/sq. mile to outlying areas with near zero. This trend is expected to continue to the end of the century.

Base Load Considerations

At the present time, electric utilities are faced with the financial and operational problems of providing roughly two kilowatts of installed capacity for each kilowatt of average load. Ideally,

PROJECTIONS OF U.S. NON-COINCIDENT PEAK ELECTRIC POWER DEMAND



1. Extrapolation of 1970-1990 Forecasts Prepared by Six Regional Advisory Committees for the Federal Power Commission. Summarized in FPC News Release No. 16323, Issued September 24, 1969.
2. *Electrical World* Forecast (July 6, 1970 issue)

FIGURE F-2

R & D Goals Task Force Report to the Electric Research Council June, 1971

Table F-II
UNITED STATES[1]
ELECTRIC UTILITY POWER REQUIREMENTS BY CATEGORIES OF USE 1965-2000 (MILLIONS OF KILOWATT HOURS)

Category of Use[2]	1965 Actual FPC	1970 Estimate FPC	1970 Estimate Elec World	1980 Estimate FPC	1980 Estimate Elec World	1990 Estimate FPC	1990 Estimate Elec World	2000 Extra-polation	2000 Estimate Elec World
Farms[3]	26,974	36,718	39,960	60,471	64,680	96,790	94,113	150,024	128,060
Irrigation & Drainage Pumping	10,917	14,946	14,985	22,762	24,321	34,779	33,571	53,316	45,489
Residential (Non-Farm)	255,281	381,262	416,250	758,849	811,140	1,416,623	1,377,549	2,469,600	2,108,070
Commercial	190,916	279,149	304,695	578,378	618,420	1,141,697	1,110,052	2,141,824	1,827,525
Industrial	436,434	613,550	667,665	1,260,145	1,347,390	2,392,820	2,326,641	4,187,435	3,574,426
Street & Highway Lighting	9,159	12,841	14,985	23,355	24,948	40,388	39,261	66,236	56,552
Electrified Transportation	4,885	5,418	6,660	6,995	7,491	8,435	8,193	9.447	10,620
Other Uses	33,004	48,280	53,280	106,350	113,850	216,242	210,200	402,210	341,698
Losses & Unaccounted For	92,009	135,155	146,520	268,995	287,760	504,406	490,420	887,545	757,560
TOTAL	1,059,579	1,527,319	1,665,000	3,086,300	3,300,000	5,852,180	5,690,000	10,367,637	8,850,000

1 Includes Alaska and Hawaii

2 Category of use for Electrical World Projection assumed same as FPC Projection on a percentage basis.

3 Includes farms actually used for farming; other residential uses in farming areas included under "Residential"

an electric utility would prefer to operate at a high daily load factor with a minimum of expensive peaking equipment for daily load variations. A possible solution to the problem is the development of loads which will fit into the minimum or base load pattern without greatly increased cost. It also would be desirable to improve the weekly and annual load factors.

During the next thirty years by promotional and other incentives, perhaps the electric utilities will be able to increase their base loads and reduce peak requirements resulting in a better utilization of resources. Increasing the utilization factor from roughly 50 per cent to a possible 60 or 70 per cent could be considered a desirable objective.

RECOMMENDED AREAS OF RESEARCH

1. Initiate a national effort to continuously update the energy fuel requirements of the utilities for a 30-year period.
2. Initiate an industry task force to explore ways and means of improving load factor. Members of this task force should be chosen on a regional and interregional basis.
3. On a national scale identify the projected load densities in the various regions of the United States and make this information available to the local, regional and national planning boards, as it may relate to national load use policy.

Much additional basic research in fuels and other energy sources is necessary. The Electric Research Council should cooperate (financially and by participation) with energy source suppliers and government agencies (such as the U.S. Office of Coal Research, Bureau of Mines, and the Atomic Energy Commission) in research to convert natural fuels to better forms for transportation and use in electric utility energy conversion processes.

APPENDIX F

PART II

CHAPTER 6 –
INDUSTRY GROWTH AND SYSTEM DEVELOPMENT
ENERGY SOURCES

Terminology

An "infinite or renewable energy source" is one which cycles and renews at a rate fast enough such that man's exploitation of that source does not affect seriously the total quantity of that resource on the earth at any time. A "finite or non-renewable energy source", on the other hand, is one in which this cycling or renewing rate is too slow (or is nonexistent) to keep up with man's exploitation rate. These finite resources are thus in the process of being depleted when utilization exists.

A summary of fuel resources and reserves together with definitions of these terms are given at the end of this section. Fuel "reserve" is defined as that fuel which is available under prevailing technological, economic and other social conditions. Fuel "resource" is that fuel which can be made available under certain assumed technological and other economic conditions.

FOSSIL FUELS

Fossil fuels are carbon deposits held beneath the earth's surface since geologic history past when carbon rich organic matter was naturally buried. The cycle time of all fossil fuels is of the magnitude to place them well within the category of finite resources.

Coal

By most recent estimates, U.S. coal reserves have been put at nearly a trillion tons, U.S. resources at over 1.5 trillion tons, and world reserves at 2 trillion tons.

Although the energy in the form of coal exists in large amounts, many other important factors enter into its becoming available to use. Environmental considerations have become a predominant factor influencing not only the utilization but also the mining of coal. Low sulfur coal, available principally in western U.S., is presently at a premium to some consumers, and investigatory effort should be given to finding the wisest use for these limited reserves.

The complexity of the coal situation, including transporation, the effects of current and potential legislation regarding air quality, and mine health and safety are important factors in the coal market and must be studied further for the benefit of coal customers and to aid in making wise, future, legal decisions.

An additional factor valuable in long-range planning is the possible effect of new technology (e.g., coal gasification, MHD, SO_2 removal) on the coal picture. In this same area, a serious comparison of the economic and other values of different processes (e.g., coal gasification vs. SO_2 control in the stack) is needed.

Oil

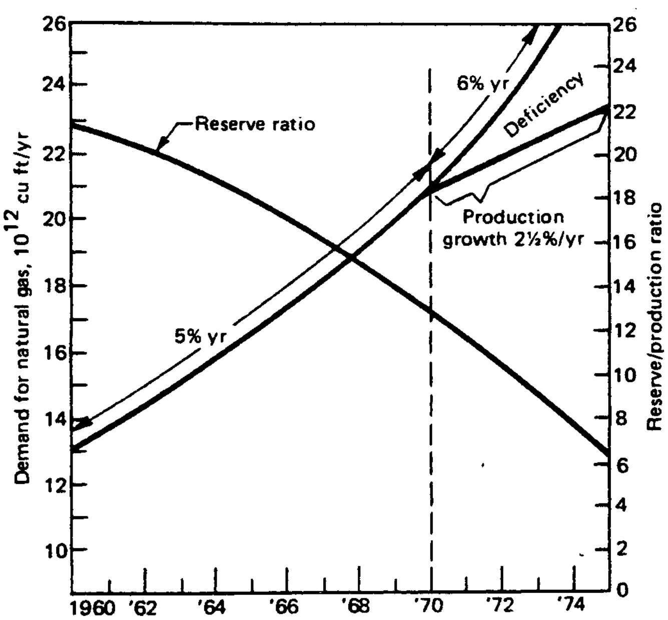
The state of oil reserves and prices could also be significantly affected by future factors, such as the advent of popular electric-powered mass transit systems or vehicles, the growth of electric heating, the conversion of coal to oil, etc. Some early study of such factors may prevent serious situations should the oil market come under the influence of one or more of them. The fact that the United States receives major portions of its oil from the middle-east and that this may be a highly unstable source due to political situations should receive more attention.

The proved reserve estimates in 1970 of the U.S. were 30 trillion barrels (42 gallon) and of the world were 527 trillion barrels. About half the 175 billion barrel resources of petroleum of the U.S. may have already been utilized. The situation may not be as bad as it seems, however, since another virtually untapped source of oil, shale oil, could be developed. However, all indications are that shale oil will be too costly to compete with other power plant fuels in the time period covered by the study.

Natural Gas

Of all the fossil fuel resources, natural gas has been viewed as the one closest to developing severe shortages. Proved reserves at the end of 1969 in the U.S. were estimated at 275 trillion cubic feet. In both 1968 and 1969, proved reserves declined for the first time, resulting in a net decrease of 19 trillion cubic feet, or nearly a year's use. The ratio of reserve to production in 1946 was 32.6. The situation over the past few years is shown in the following figure:

Natural Gas Reserve Ratio and Demand*



*Electrical World 1/15/71

Natural gas resources of the United States have been estimated today to be 1227 trillion cubic feet. Over the past decade, exploratory drilling has declined seriously (nearly 50% for some types of drilling). Much of the undiscovered gas resources are in Alaska, but possibly more lie in the offshore areas in the Gulf and Atlantic coasts. These offshore resources, in water depths up to 1500 feet, will be tapped only if deep-water drilling is developed (present technology limits drilling depths to 600 feet).

Other technology which would contribute to the natural gas reserves is "stimulation" of wells by underground nuclear explosions. The AEC has been devoting much research effort to this technique, but it, as yet, has not proven to be feasible. A severalfold increase in gas-field productivity is expected if such a program proves successful.

The world reserves of natural gas are large compared to the United States (about 1.3 quadrillion cubic feet), but transportation difficulties are limiting this country's access to them. Cryogenics applications in gas transport appear to be the most promising solution to this problem.

Methane, or gas synthesized from coal and oil, may relieve the pressures on natural gas resources in the future. Much progress has already been made on developing practical industrial gasification processes, but considerably more effort is needed to fully develop the process for economical application.

Other Carbon Fuel Sources

With the steady depletion of fossil fuel reserves becoming more apparent, some thought has been given to other sources of carbon fuel. Most of these would not only increase energy reserves but would also provide relief to pollution problems.

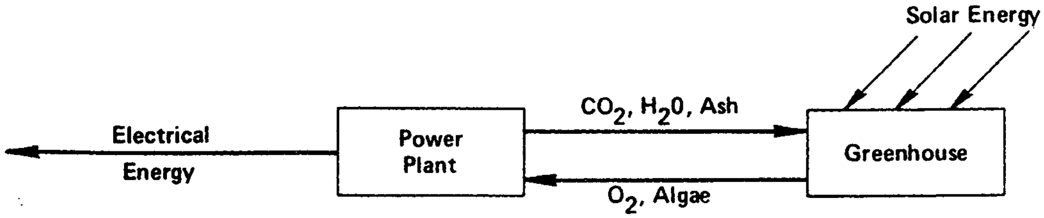
Sewage and Refuse

Although the concept of sewage and refuse as fuels may seem extraordinary to some, industry pressure for finding new fuels and public need for more acceptable means of waste disposal may jointly provide sufficient argument for its development. The technique of utilizing wastes for converstion to steam energy has been applied widely in Europe but only for refuse incineration. If this concept proves feasible, the fuel supply is conveniently near the load, but sewage and refuse would total only a small part of the total fuel required to meet electric demand. Much basic research is still needed in this area to find feasible ways of converting the raw material into quality fuel. Some success has already been reported in converting refuse to low sulfur oil of medium to high grade.

As the results of some basic research become available, an evaluation as to the significance of the waste disposal aspect toward offsetting additional cost would be beneficial in promoting further work. Also, research will be needed to determine what approaches toward utilization of these resources would prove to be the most advantageous (e.g., drying and burning, or converstion to oil or gas before combustion).

Closed-Cycle Systems

Traditionally, photoelectric solar cells and reflector panels have been thought of for converting solar energy to useful work, but biological means may also be possible. Such biological energy cycles would probably utilize algae to capture the sun's energy. After drying, the algae would be burned, and all the combustion by-products would be returned to be converted once again to algae (see figure).



Although an algae energy conversion system may be possible, the basic research has not been done. If other new methods of generation do not develop as expected, this system could become more important.

NUCLEAR FUELS

Nuclear fuels are those substances which are processed from natural occurring ores or can be made to undergo controlled nuclear fission or fusion. Although all nuclear fuels are finite, some are so common they may be considered infinite.

Fission

Uranium

Although uranium, per se, is a relatively abundant resource, only a small percentage of uranium (one part out of 140) which is fissionable in its natural state (U-235) becomes a reactor fuel with present day technology.

The forecasting of the adequacy of uranium supplies is complicated by the fact that appropriate technological devleopments could change by orders of magnitude the energy value of these resources. In present light water reactors with plutonium recycle, 1000 tons of $U_3 0_8$ is equivalent to about 4.5×10^{14} Btu. This energy value could be increased 40 - to 60 - fold (or more) if applied to as yet undeveloped breeder reactors. The timing of commercial breeder reactor availability will be a significant factor in the life of remaining uranium resources.

The pricing of uranium supplies is a very important factor in their future use as an energy source and therefore may be an item for research. Some significant changes in government regulation may be on the horizon with some substantial price regulating practices expiring in mid-1973. Also, indications of the revamping of the Atomic Energy Commission's functions should be carefully watched for their possible effects on nuclear fuel policy changes, and the advantages and disadvantages of the U.S. embargo on uranium should be evaluated.

Thorium

Thorium can be converted to U-233 which is fissionable; however, reactor technology is not presently available to make economic use of this material as a major fuel.

Measured and inferred deposits in the free world of $Th0_2$, from which thorium can be produced at prices comparable to those for uranium, are estimated to be 600,000 tons in the western U.S. and some 1.5 million tons worldwide. As a measure of perspective, the AEC has forecast the demand for thorium to be low throughout the 70's, but by 1980 an annual market of 500 tons of $Th0_2$ might prevail if either or both the molten salt or the high-temperature gas-cooled breeder reactors prove successful. By 1990, that market could increase to 3000 tons per year if the thorium-fueled reactors are successfully developed.

The stable market now present for nonfuel uses of thorium might be monitored for excessive utilization of this valuable fuel resource.

Fusion

Deuterium

The essential fuel material for any fusion reactions is an isotope of hydrogen called deuterium (D), which occurs naturally at one atom per 6500 atoms of ordinary hydrogen.

The method of extracting deuterium from water appears to be well developed. It costs about 4 cents to extract all of the D from a gallon of water at present. The properties of pure water remain unchanged with the removal of the heavy hydrogen atoms so there is probably no need to be concerned about that aspect.

Energy from the so-called "D-D" fusion reaction has been calculated to show that the deuterium present in one cubic meter of water is equivalent to 1,360 barrels of crude oil. The energy content of the deuterium which could be withdrawn from the oceans of the world to reduce the oceans' initial concentration of deuterium 1% would equal about 500,000 times that of the world's initial supply of fossil fuels.

Tritium

Due to the larger problems associated with the D-D fusion reaction, a D-T reaction will in all probability be the only feasible means of fusion for some time. Tritium (T), like deuterium, is an isotope of hydrogen but with an atomic mass of three.

Unlike deuterium, tritium is very rare in nature and must be synthesized. The only feasible means of synthesizing tritium presently known is by the interaction of deuterium with lithium-6 nuclei. Research should proceed on investigations of other methods to economically produce tritium.

Lithium

Lithium appears to be an essential constituent in at least the early phases of any fusion reactor program. Natural lithium, of which only 7.42% is the fusion-required isotope Li-6 is a mineral and must be refined from earthen ore.

The measured and indicated reserves of lithium in the United States total about 2.8 million tons, and the world reserves may be some 5 million tons. A comparison of this figure with resource estimates of deuterium strongly indicates that the amount of energy potentially available from fusion reactors requiring lithium will be limited by the scarcity of Li-6 to approximately the energy obtainable from the combustion of the world's supply of fossil fuel resources. Lithium available from sea water may yield resources of several magnitudes greater than that from terrestrial sources.

NONFUEL ENERGY SOURCES

Those energy sources which are either kinetic power available on the earth's surface or derived directly from the sun, are classified here as nonfuel sources. In general, most nonfuel energy sources may be thought of as infinite because of their short cycle time.

Hydroelectric Power

Using U.S. Geological Survey data, the Federal Power Commission has estimated the U.S. hydroelectric power resource base at 160,000 to 170,000 MW and the world resource base at some 2,800,000 MW. Of this, about 50,000 MW of U.S. hydroelectric power is developed. For all its attractiveness – renewable, fast start-up, peaking value, etc. – the fact remains that most feasible hydro resources in this country have already been developed and the bulk of remaining hydro resources are on marginal sites. Further, the use or value of natural waterways is broader than simply as a resource for hydroelectric power. A river's worth as a free flowing, natural stream must be evaluated. A hydroelectric facility may, of course, be environmentally beneficial in certain instances, but each prospective site must be evaluated for implications concerning broader environmental impact.

Geothermal

The development of geothermal resources is finding support among many citizens because of its apparently pollution-free status. Currently, about 1,000 MWe worldwide is produced by geothermal installations. The total resource of geothermal energy has been estimated to be 3 million MW-years, with 5% or 10% of this in the United States. Investigations and experience in California may lead to significant increased use of this resource.

Tidal Power

The tides may certainly be considered an infinite energy source, and rather thorough surveys have placed their total world average potential power at nearly 64,000 MW, or slightly greater than 2% of the world's potential water power. Presently, on the order of a few hundred MW capacity is installed in France and Russia, with upwards of a thousand MW in the planning stage around the world.

Although this resource may be exploited without the usual consumption of limited resources of polluting qualities, the ecologic consequences of this method of energy production may be great and should be explored further. The use of tides for energy production will, in many instances, conflict strongly with other important uses of ocean resources (e.g., food production and shipping).

Solar Energy

Outside the earth's atmosphere the power received continuously as electromagnetic radiation from the sun (known as the "solar constant") is about 1.4 kW per square meter. The daily average of sun power at the earth's surface in a bright location is less than 20% of the solar constant because of atmospheric scattering and non-productive hours of the day.

Prior to the space program, the possibility of solar energy collection was limited to earth-bound devices. The intensity and reliability of solar energy at this point is limited further than already mentioned by periodic obstruction by clouds, atmospheric dust, and effects of wind and weather on the collection facilities. Methods of direct conversion of this resource to electricity have many material and technological limitations; however, a great number of other more feasible uses of solar energy are possible and practical for non-industrialized countries.

With the availability of space technology, orbiting systems have been proposed which avert most of the land-based solar resource availability problems. Irrespective of technological problems, the energy resource availability of such systems is virtually unlimited.

Wind Power

The United States could not significantly add to its energy sources with domestic wind power development.

Summary of Fuel Resources

United States and World Fuels – Btu Content (Figures in quadrillion (10^{15}) Btu's)

	United States		World
	Reserve*	Resource**	Reserve*
Coal	18,258	33,705	56,833
Petroleum	174	2,382	3,062
Natural Gas	284	1,268	1,355
Natural Gas Liquids	38	300	–
Shale Oil	464	58,000	580,000
Uranium Oxide	92	288	850

The 1970 United States energy demand for all uses was 68.810 quadrillion Btu's

The research required from an energy sources viewpoint can be put into three categories:

1. *Energy source forecasting* which includes evaluation of resource and reserve capacity, development of cost schedule, and defining of problems associated with the delivery of each fuel. This portion of the research effort is probably the most essential to future energy use development.
2. *Energy source quality* which considers the environmental implications of each source and what technological developments would be most valuable to lessen the detrimental effects of energy utilization.
3. *"Value engineering"* which assumes knowledge of the first two research categories and addresses itself to questions of long-range social concern. Answers to the questions, "Which fuel should be used by which users for maximum social benefit?", and, "Should energy sources be conserved for future generations, and how?", are of underlying value and should receive research effort.

*Fuel reserve is that fuel which is available under prevailing technological, economic, and social conditions.

**Fuel resource is that fuel which can be made available under certain assumed technological and economic conditions.

ENERGY SOURCES
BIBILOGRAPHY

General

1. "Energy Resources", M.K. Hubbert, *Resources and Man – A Study and Recommendations,* W.H. Freemand and Co., 1969
2. "Commodity Data Summaries", U.S. Bureau of Mines, January 1971
3. "U.S. Energy Policies – An Agenda for Research", Resources For The Future, Inc., John Hopkins Press, 1968
4. "Mineral Facts and Problems", U.S. Bureau of Mines Bulletin 630, 1965
5. "Selected Sources of Information on United States and World Energy Resources: An Annotated Bibliography", U.S. Geological Survey Circular 641, 1970

Terminology

6. "Energy in the American Economy", Resources For The Future, Inc., John Hopkins Press, 1960

Coal

7. "Coal Picture Is Not All Black", *Electric Light and Power,* Jan. 1971, pp 39-41

Oil

8. "Organic-Rich Shale of the United States and World Land Areas", U.S. Geological Survey Circular 523, 1965
9. "Forecast-Review Report", *Oil and Gas Journal,* V. 68, No. 4, 1970, pp 113-139

Natural Gas

10. "Joint Action Needed to Solve the Fuel Problem", *Electrical World,* January 15, 1971, pp 38-40

Sewage and Refuse

11. "The Detroit Edison Company Advanced Projects Committee Newsletter", Jan. 1971

Uranium and Thorium

12. "The Nuclear Industry", Atomic Energy Commission, Government Printing Office, 1966 through 1970

Lithium

13. "Thermonuclear Reactor and Electric Power Generation, A Survey", Blake Myers, presented at 5th Intersociety Energy Conversion Conf, Las Vegas, Sept. 1970

Hydro

14. "Hydroelectric Power Evaluation", U.S. Federal Power Commission Publication FPC-P-35, 1968.

APPENDIX F

PART III

CHAPTER 6
INDUSTRY GROWTH AND SYSTEM DEVELOPMENT

ENERGY TRANSPORT SYSTEMS

Energy transportation costs for electric transmission as well as the cost of transporting nuclear fuel by barge, rail and truck; gas, coal and oil by pipeline; coal by rail and barge; and oil by tanker will be considered. These costs are listed in Table F-III for ease of comparison. When comparing energy transportation costs on a cents/million BTU/100 miles basis fossil fuel transportation appears to have almost a three to one advantage over electric transmission. However, our interest is in converting these fuels into electrical energy for final use. Considering thermal efficiencies of fossil plants, we see that energy transmission costs of fossil fuels and electric transmission are competitive (e.g., mine-mouth generation). This section will present comparative costs for 60 Hertz ac and dc transmission of electric power both aerial and underground, at several voltage levels, followed by energy transport by pipeline, rail, water and highway.

Little data are available concerning future costs of energy transportation. The cost of electric power transmission in urban areas will increase in the future due to escalating right-of-way expenses and environmental pressures to install underground transmission. Changes in the relative costs of various energy transportation systems affect economic considerations in planning future generation sites, the type of generation installed and the energy transport system adopted. New concepts for energy transport systems should be studied, such as hydrogen gas pipelines or coal slurries using a gaseous fluid such as methane in place of liquid mediums currently being used. The best opportunities for improvements and cost reduction in energy transportation systems exist in terminal design and underground line construction.

Research expenditures on the order of $100,000 annually are recommended to determine future trends in energy transportation costs, as well as the probable development of new concepts for energy transportation systems.

ELECTRIC POWER TRANSMISSION

The cost of electric power transmission varies considerably with terrain to be crossed, right of way costs, labor costs, line voltage and line capacity. Experience has shown that dc lines will cost approximately .65 to .75 times as much as an ac overhead line of comparable capacity exclusive of terminal equipment.[8] Transmission costs for blocks of ac and dc power are presented for several voltage levels in Table F-IV[9].

Cost ratios for underground to aerial transmission for equal capacity lines range from ten to one to forty to one. Labor and right-of-way costs as well as the type of cable systems and terrain being traversed affect this ratio.

TABLE F-III
COMPARISON OF ENERGY TRANSPORTATION COSTS

	Capacity	Capacity in 10^{12}BTU/Day	Cents/Million BTU/100 Miles
Pipeline – Gas	1,000 – 5,000 MMscfd.	1 – 5	1.5 – 2
Pipeline – LNG	500 – 1,500 MMscfd.	0.5	1.5 – 3
Pipeline – Oil	300,000 – 1,200,000 barrels/day	20 – 75	0.3 – 0.8
Pipeline – Coal	3–15 million tons annually	0.2 – 1	1.3 – 3.8
Barge – Coal	900 – 1,400 tons/barge	– –	1.2 – 1.7
Tanker – Oil	100 – 300 thousand deadweight tons	– –	0.5
Rail – Coal	70 – 100 tons per car	– –	4 – 6
Unit Train – Coal	3 million tons annually	0.2	2.5
Highway – Coal	10 – 20 tons per truckload	– –	9 – 18
Electric	600 – 1,000 MW	0.1	7 – 14

TABLE F-IV
COST OF ELECTRIC TRANSMISSION*

KV	MW	Miles Transmitted	Cents/10^6BTU/100 Miles 70% Local Factor	85% Load Factor
500 AC	1000	1000	10.2	8.8
700 AC	2000	1000	9.2	7.8
±250 DC	600	600	13.9	12.2
±375 DC	900	1000	9.8	8.4
±500 DC	1200	1000	9.2	7.7

*These data include terminal equipment (see reference 9)

PIPELINES

In the following analysis, costs for transporting gas, oil and coal slurry by pipeline will be presented with transportation costs divided into fixed as well as operating and maintenance costs.

Considering a high capacity gas pipeline (1,000-5,000 MMscfd.), transmission charges for a large diameter (26-36"), long distance pipeline with a high load factor (85% or more) will cost 1.5 to 2.0 cents/million BTU/100 miles.[10] Fixed costs make up 75% of these charges with operating and maintenance costs making up the remainder.

Transmission costs for high capacity (500-1,500 MMscfd). LNG pipelines range from 1.5 to 3 cents/million BTU/100 miles.[11]

Oil transportation by pipeline costs between .3 to .8 cents/million BTU/100 miles.[12] These costs are for 30-36 inch diameter pipelines capable of transporting 300,000-1,200,000 barrels of oil per day.

Data are available for two coal slurry pipelines. A 108 mile long, 10" pipeline from Cadiz to Cleveland, Ohio, was operated from January 1958 until the spring of 1963.[13] The line was capable of moving 1½ million tons of coal a year, at 3.8 cents/million BTU/100 miles. The Black Mesa Pipeline from Arizona to Nevada is an 18" diameter, 275 mile-long pipeline capable of moving 5.8 million tons of coal annually. Transportation costs for this line will range between 2 and 3 cents/million BTU/100 miles. Estimated operating costs for coal slurry pipelines are shown in Table F-V.[14]

TABLE F-V
ESTIMATED COST FOR COAL – SLURRY PIPELINES

	QUANTITY, TONS OF COAL PER YEAR										
	6 Million				9 Million				15 Million		
Distance in Miles	250	500	750	1,000	250	500	750	1,000	250	750	1,000
Total in cents/million Btu/100 miles	2.86	2.2	1.98	1.87	2.5	1.9	1.68	1.58	2.18	1.38	1.28

RAIL TRANSPORTATION

Rail charges for distances of 600 to 1,000 miles are approximately 4-6 cents/million BTU/100 miles.[15] These figures do not contain any operating improvements such as unit trains or efficient high speed terminal facilities. The estimated cost for a 100 car unit train with 85 ton capacity cars is approximately 2.5 cents/million BTU/100 miles. This is for an annual shipment of three million tons of coal and could be reduced by increasing the amount of coal transported.

WATER TRANSPORTATION

Water transportation is used for moving coal by barge and oil by tanker. Standard size barges carry 900 to 1,400 tons of coal. Transportation rates range from 1.2 to 1.7 cents/million BTU/100 miles.[13] Economies of scale are found in this form of coal transportation and larger barges with more powerful tow boats are being used. Decreases of 10% to 30% are possible depending on the distance involved. Barge crews could be reduced in size, providing a further reduction in costs. Oil shipment by tankers with a capacity of 100,000 to 300,000 deadweight tons costs less than .5 cents/million BTU/100 miles.[16] However, the per mile cost exaggerates the tanker's advantages, since the tanker may have to travel 2 to 2½ times as far as the pipeline.

HIGHWAY TRANSPORTATION

Transportation cost for coal trucks of 10 to 20 ton capacity for short hauls has been estimated 9.6 to 19.6 cents/million BTU/100 miles depending on distances.[13]

NUCLEAR FUEL TRANSPORTATION[17]

Engineering and safety considerations limit methods for transporting spent fuel casks to barge, rail and truck. Typical truck casks for power reactor fuel elements are 5 to 6 feet in diameter and 16 feet long. This is assuming that the elements have been allowed to cool for 120 to 180 days.

Barge transportation may be feasible. However, larger and sturdier barges will have to be constructed. These barges will have to demonstrate a much better safety record than barges used for conventional cargo transportation.

TABLE F-VI
ESTIMATE OF SPENT FUEL SHIPPING REQUIREMENTS THROUGH 1980[17]

Calendar Year	Kg U In Spent Fuel Shipped	No. of Assemblies Shipped	Total Est. Tons Spent Fuel
1970	55,000	250	70
1975	1,125,000	5,000	1,500
1980	2,950,000	15,000	3,800

It should be feasible to transport up to 10 PWR elements or 20 BWR elements at one time by rail. However, at this time liability restrictions imposed by some railroads make it impossible to transport spent fuel elements by rail in some parts of the United States.

Highways are the primary method of transporting fuel elements. Economic considerations make it preferable to ship as many elements at one time as possible. However the load limit of state highways limits the combined weight of the vehicle and load to 73,000 lbs. In the past overload permits have been granted but these restrict travel to eight hours per day and exclude weekend travel making overweight transportation uneconomical. It appears that in the future these permits will not be granted, thus restricting shipments to 1 to 4 elements at a time, i.e., one to two elements for a PWR, and two to four elements for a BWR. These restrictions will force fuel transportation to be a year round task. Table F-VI projects the number of fuel assemblies which will have been shipped through 1980.

APPENDIX F

PART IV

REFERENCES FOR CHAPTER 6
INDUSTRY GROWTH AND SYSTEM DEVELOPMENT

1. Sporn, Philip, "For Utilities the Future is a Systems Problem", Electrical World, January 1, 1971.
2. Smith, H.L., "Changing Generation Patterns", *Power Engineering,* November, 1970.
3. Panel Discussion Moderated by John Papamareos, "Power for Tomorrow, What Are Our Options?' *Power Engineering,* October, 1970.
4. NERC-TAC Task Force Report on Interregional Reliability.
5. Oak Ridge National Laboratory, "Nuclear Energy Centers Industrial and Agro-Industrial Complexes Summary Report", ORNL-4291, May 21-22, 1970.
6. Bureau of Census – Population Estimates and Projections No. 448, August 6, 1970. Series D.
7. "A Review and Comparison of Selected United States Energy Forecasts" by Pacific Northwest Laboratories of Battelle Memorial Institute, December 1969. This review is a compilation of a series of individual comparable reports on energy projections made during recent years.
8. *The Transmission of Electric Power,* The Technical Advisory Committee on Transmission for the National Power Survey, October 1970.
9. National Power Survey, Federal Power Commission 1964, Advisory Committee Report No. 16, Cost of Electrical Energy Transmission by AC and DC Extra High Voltage, pp. 191-203.
10. *Report of the National Fuels and Energy Study Group,* on An Assessment of Available Information on Energy in the United States to the Committee on Interior and Insular Affairs, United States Senate, September 21, 1962, p. 160.
11. Hoover, Thomas E., "Technical Feasibility and Cost of LNG pipelines", *Pipeline News,* pp. 10-16, Dec. 1970.
12. *Report of National Fuels and Energy Study Group,* on An Assessment of Available Information on Energy in the United States to the Committee on Interior and Insular Affairs, United States Senate, September 21, 1962, p. 163.

13. *Energy R&D and National Progress,* prepared for the Interdepartment Energy Study by the Energy Study Group under the direction of Ali Bulent Cambel, 1964, p. 131.

14. Perry, Harry, Revolution in Coal Transport. Is It Near? Mechanization, v. 27, No. 5, May 1963, pp. 29-33.

15. *Energy R&D and National Progress,* prepared for the Interdepartment Energy Study by the Energy Study Group under the direction of Ali Bulent Cambel, 1964, p. 228.

16. Landsberg, Hans H. and Schurr, Sam H., *Energy in the United States* Sources, Uses and Policy Issues, 1963, Random House, p. 22.

17. The Nuclear Industry, 1970, by the A.E.C., pp. 324-327.