WASH-1281

THE NATION'S ENERGY FUTURE

A REPORT TO RICHARD M. NIXON PRESIDENT OF THE UNITED STATES

1 DECEMBER 1973

MASTER

Submitted by Dr. Dixy Lee Ray
Chairman, United States Atomic Energy Commission

DISCLAIMER

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

OFFICE OF THE CHAIRMAN

December 1, 1973

The President
The White House

Dear Mr. President:

In response to your directive of 29 June of this year, viz:

> " . . . I am directing the Chairman of the Atomic Energy Commission to undertake an immediate review of Federal and private energy research and development activities, under the general direction of the Energy Policy Office, and to recommend an integrated energy research and development program for the Nation. . . . By December 1 of this year, I am asking for her recommendations for energy research and development programs which should be included in my fiscal year 1975 budget."

I am pleased to present this Report.

As requested, the Report was developed under the general guidance of the Energy Policy Office. It has also benefited from the active participation of those Federal Agencies most concerned with energy research. Additionally, there has been widespread consultation with representatives of the private sector, including a broad range of energy industries. A more detailed description of the procedures that were followed and a listing of those persons most directly involved are attached hereto.

Any merit the Report may have deserves to be widely shared with those who devoted their time, energy, and talent to its development. Any shortcomings are my responsibility alone. Formal concurrence in the recommendations was not requested from either individuals or agencies; the final recommendations are based on all

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the information gathered and result from my considered judgment of the kind of thoughtful, well-considered energy research and development program that this Nation urgently needs to pursue.

Considerations for using today's technology to meet and overcome the present energy crisis, and to be responsive to "Project Independence", are being submitted separately.

I earnestly hope that this Report will be helpful in your efforts to mobilize the Nation's resources toward the attainment of a capacity for energy self-sufficiency by 1980. I believe that, in surmounting this challenge, the Nation can emerge stronger and more free than ever before to pursue with renewed vigor its high aims of domestic and international peace and well being.

Respectfully yours,

Chairman

Attachment

ATTACHMENT

UNITED STATES ENERGY RESEARCH AND DEVELOPMENT PROGRAM

This report is based upon the results of several major and somewhat independent efforts:

- A group of Energy Workshops, organized under the sponsorship of Cornell University, considered the major directions and overall framework required for a national program. Specific workshop topics and the membership of each are shown in Appendix C of the Report. The deliberations will be separately published.

- Sixteen Technical Review Panels were established. These were made up of 121 Federal employees from thirty-six Departments and Agencies assisted by 282 consultants from the private sector. More than 1100 specific proposals for the energy research and development program were reviewed and evaluated. Membership of the panels and the consultants employed are listed in Appendix C.

- Review of the results from the Workshops and the Technical Panels was conducted by an Overview Panel chaired by Mr. Stephen A. Wakefield, Assistant Secretary for Energy and Minerals, Department of the Interior. The membership included:

  Mr. William E. Simon, Deputy Secretary of the Treasury

  Dr. Beatrice E. Willard, Member, Council of Environmental Quality

  Dr. Betsy Ancker-Johnson, Assistant Secretary for Science and Technology, Department of Commerce

  Dr. Stanley M. Greenfield, Assistant Administrator for Research and Development, Environmental Protection Agency

Mr. William A. Anders, Commissioner, Atomic Energy Commission

Mr. Bruce T. Lundin, Director, Lewis Research Center, National Aeronautics and Space Administration

Mr. John P. Abbadessa, Controller, Atomic Energy Commission

The Overview Panel made specific recommendations on the composition of the ten billion dollar, five year program and on the fiscal year 1975 budget.

- A draft of the report was sent to more than 100 individuals for comment. It also went to all concerned government Departments and Agencies.

- I consulted personally with numerous leaders in government, industry, and the scientific community throughout the period of the Report's preparation.

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Table of Contents

List of Tables and Figures

EXECUTIVE SUMMARY

Purpose:

The Report, directed by the President in his June 29, 1973, Statement on Energy, recommends:

- A national energy research and development (ER&D) program.
- A five-year, $10 billion Federal ER&D program.
- The FY 1975 Federal budget for ER&D.

Findings:

- Present energy problems stem, in large part, from the lack of a coordinated national ER&D program over the last 20 years. Only nuclear power has received sustained support at adequate levels.

- The requirement to regain and maintain energy self-sufficiency stems from conditions more fundamental than the current crisis. Worldwide energy shortages impend as energy-intensive industrial growth spreads and accelerates.

- The United States has the resources and technology for self-sufficiency. A properly directed, sustained national commitment can attain that goal.

- Five tasks are required to regain and sustain self-sufficiency, and simultaneous effort is urgently required on all five. Their contributions to self-sufficiency will begin to materialize in the order listed:

  Task 1. Conserve energy by reducing consumption and conserve energy resources by increasing the technical efficiency of conversion processes.
  Task 2. Increase domestic production of oil and natural gas as rapidly as possible.
  Task 3. Increase the use of coal, first to supplement and later to replace oil and natural gas.
  Task 4. Expand the production of nuclear energy as rapidly as possible, first to supplement and later to replace fossil energy.
  Task 5. Promote, to the maximum extent feasible, the use of renewable energy sources (hydro, geothermal, solar) and pursue the promise of fusion and central station solar power.

- The recommended program, based on what is now known, is both necessary and sufficient to maximize ER&D's contribution to the Nation's energy goals. Even so, 1985 is the earliest date by which self-sufficiency can reasonably be expected with this program.

- By 1980, the recommended ER&D program is expected to reduce oil imports to half (6 million barrels/day) of those currently projected. Other extraordinary measures will be required to restrict consumption, increase domestic production, or both by enough to displace the other half.

Recommendations:

- The national and Federal ER&D programs, FY 1975-1979, and the FY 1975 Federal ER&D budget are shown in the table below. (The FY 1974 Federal ER&D budget is shown for comparison.)

ER&D PROGRAM AND BUDGET RECOMMENDATIONS
($ Millions)

	ER&D Programs, FY 1975-1979			Federal ER&D Budget	
Self-Sufficiency Tasks	Total Required	Private Expected	Federal Recommended	FY 1974 Planned	FY 1975 Recommended
1. Conserve Energy and Energy Resources	4,940	3,500	1,440	62.3	166.2
2. Produce Oil and Natural Gas	4,960	4,500	460	19.5	51.7
3. Produce and Use Coal	5,175	3,000	2,175	167.2	405.0
4. Produce Nuclear Energy	5,340	1,250	4,090	517.3	731.7
5. Use Other Sources, Pursue Future Prospects	2,085	250	1,835	123.0	217.5
TOTAL	22,500	12,500	10,000	889.3	1,572.1

- Establish an operational Energy Research and Development Administration not later than July 1, 1974, to plan and coordinate the total program and to direct the major share of the Federal program.

- Conduct a comprehensive program review at least annually, reallocating funds among programs as required. Increase the total program only if reallocations are insufficient to fund all highly promising prospects.

- Ensure full consideration of the energy consequences of all Federal actions taken to achieve nonenergy goals.

- Maximize private-sector involvement in the conduct, review, and evaluation of the Federal ER&D program, both to conserve Federal dollars and to speed up the application of technological advances.

- Initiate in FY 1975 a Synthetic Fuels Pioneer Program: privately funded construction, induced by loans or price guarantees, of several full-scale commercial plants for producing synthetic fuels from coal using existing technologies. Federal ER&D funds would be used to collect and disseminate engineering, economic, and environmental data that would serve as benchmarks for evaluating new developments. The program would lay the groundwork for a rapid expansion of domestic energy production capacity and focus ER&D effort, Federal and private, on highest priority problems.

- Accelerate ongoing work in three supporting programs that contribute to the goals of the recommended ER&D program:

1. Environmental Effects Research	$650 Million
2. Basic Research	300 Million
3. Manpower Development	50 Million
	$1000 Million

1

Purpose and Scope

This report is prepared in response to the President's directive in his June 29, 1973, energy message. Its purpose is to recommend:

- The national energy research and development program needed to regain and maintain energy self-sufficiency.
- The five-year, $10 billion Federal energy research and development program to supplement research and development expenditures expected from the private sector.
- The Fiscal Year 1975 Federal energy research and development budget.

Since the President's directive was announced, the Nation has become acutely aware that shortages of energy–especially oil–threaten its social, economic, and environmental priorities. The energy shortages of today and those projected for future decades stem, in part, from the lack of a coordinated national program for energy research and development over the past 10 to 20 years. Today's impending shortages impart a long overdue sense of urgency to the effort being launched to meet not only immediate requirements but also the growing needs of the years ahead.

The challenge posed by the immediate energy future carries with it an unparalleled opportunity to emerge better equipped than ever before to pursue the Nation's higher goals of domestic and international peace and prosperity. The Nation has long had the human and material resources to surmount the present challenge and seize its corresponding opportunity; the widespread awareness of the necessity to do so can now provide the essential will to convert its potential into practice.

This report is based on a series of studies carried out under the guidance of the Energy Policy Office in conjunction with Government departments and agencies having energy responsibilities. People from industry, foundations, and the academic community were also consulted, together with other private citizens having responsibilities and acknowledged expertise in the energy field.

A number of issues had to be dealt with to limit the scope of the report to energy research and development. The most important were:

- The role of energy in our society.
- The relationship of energy research and development to energy policy.
- The distinction between energy research and development and energy production.
- The impact of research and development and other energy policy actions on the future of the Nation's energy system.
- The necessity to support energy development with an expansion of environmental effects research, basic research, and manpower development.
- The consequences of energy policies aimed at attaining other goals, such as economic growth, consumer protection, and land use

THE ROLE OF ENERGY IN OUR SOCIETY

Energy is the *sine qua non* of a modern society's ability to do the things it wants to do. Such goals as maintaining the standard of living for a growing population, national security, improved quality of life, increased affluence, and increased assistance to less developed societies can only be attained with increasingly large amounts of energy. While lower energy costs allow a society more freedom of action in seeking its goals, the availability of energy is the first requirement of having any freedom of action at all.

RESEARCH AND DEVELOPMENT: ONE PART OF POLICY

Federal energy policy comprises those actions that aim to have a direct impact on the Nation's energy system by increasing supply, reducing demand, or changing production and use patterns. For example, one possible policy is to let the market determine what goes on in the energy system. Another policy is to intervene by rationing, price controls, mandatory allocations, price guarantees, and other nonmarket measures to change certain operations of the market and presumably the results for the economy.

The aim of Federal energy policy is to ensure that the Nation's ability to pursue its higher order goals is not unduly impaired by energy shortages.

To respond to current problems, policy-makers must select from among a set of actions limited by existing physical and institutional constraints. However, energy research and development actions can be taken now that will expand the range of actions that will be possible in the future.

By its nature energy research and development is an investment in the Nation's future. Numerous opportunities for research that would yield early results exist and should be pursued vigorously; a major part of the recommended program is designed to remove obstacles to the attainment of energy self-sufficiency by 1980. Still, a program aimed only at the immediate future would be less than fully responsive to the Nation's needs. Major improvements in the energy situation can come only from sustained effort over an extended time because long lead times are required to improve the technologies for producing and using energy. Accordingly the recommended program was designed to meet the Nation's energy needs in the years beyond 1980, as well as to make the maximum possible contribution to the Nation's immediate energy goals.

RESEARCH AND DEVELOPMENT VS. PRODUCTION

Research and development activities extend from fundamental research on the properties of matter to successful demonstration on a commercial scale of the technical and economic feasibility of new processes. The application of new processes on a scale big enough to make a significant impact on the energy system is production, not research and development. A vigorous program for increasing energy production in the immediate future is urgently needed to move toward self-sufficiency. Such a program must rely primarily on existing technologies—not on research and development. Although some "quick fixes" of particular engineering problems in producing energy might be considered research and development, the bulk of the research and development program cannot be expected to make big differences in energy **production** rates in any short time.

The dividing line between research and development and production is not absolute; the two can be mutually supportive. Nothing identifies specific needs for immediate research and development attention more quickly than a major production program, and few actions can have as much short-term impact on a major production program as top priority research and development to remove production bottlenecks. The Manhattan Project of World War II is a classic example of how these two kinds of effort can be integrated and applied toward rapid attainment of a specific goal. Still, a balanced research and development program must not be limited only to efforts aimed at supporting immediate production programs; it must also include those efforts aimed at making possible the production programs that will be needed in the future.

RESEARCH AND DEVELOPMENT, POLICY, AND THE NATION'S ENERGY FUTURE

The national energy research and development program begun now and carried out over the next few years is a principal vehicle for shaping the evolution of the Nation's energy system. What is done and not done in that program will define the technological boundaries of future energy policy choices. Accordingly, obtaining agreement on how the energy system should evolve is the first step in designing an energy research and development program.

Energy policies other than research and development will also be required if the energy future is to evolve in the desired direction. Some energy policy decisions will be necessary to support research and development. Other decisions will be needed to foster the application of new technologies after commercial feasibility has been demonstrated. Still other policies aimed at goals outside the energy system will influence both the execution of the research and development program and the implementation of new technologies derived from it.

SUPPORTING PROGRAMS

The evolution of the energy system will be heavily influenced by policies not directly aimed at energy questions, e.g., environmental effects, basic research, and manpower development policies. Because of their close relationship to energy, specific programs in these areas are recommended for levels of **incremental** funding in addition to the $10 billion energy research and development program. The recommended increments to these supporting programs are considered the **minimums** required to guarantee both the successful conduct of the proposed energy research and development and the rapid implementation of its results throughout the energy system.

OTHER POLICY ACTIONS

Because energy plays such a central role in our society, a number of policy actions on nonenergy goals will affect the energy system. Some areas where policy actions affect the energy system are rate regulation, price controls, antitrust and patent laws, land-use laws, and leasing of public lands.

Because decisions on these policies involve a wide range of considerations outside energy matters, this report refers only to their implications and merely suggests directions that will facilitate energy research and development and help realize its benefits.

SYNOPSIS

Chapter 2 summarizes the recommended five-year $10 billion Federal program, details of which are in Appendix A, and presents the recommended Fiscal Year 1975 budget, the first increment of the recommended program.

Chapter 3 summarizes the energy supply and demand situation and indicates how much change is needed to regain self-sufficiency.

Chapter 4 sets out the five major tasks required to regain and maintain energy self-sufficiency and from these tasks derives the goal of the Nation's energy research and development program.

Chapter 5 discusses the role of the Federal Government in energy research and development, including its relations with industry, its own research and development strategy, criteria for funding of Federal programs, and guidelines for managing the Federal effort.

Chapter 6 explains the technological obstacles to accomplishing the five tasks and discusses the major constraints under which the research and development program must be carried out.

Chapter 7 classifies the research and development objectives under each of the five tasks into short-, mid-, and long-term categories.

2

The Recommended Five-Year National Energy Research and Development Program

Table 2-1 summarizes the recommended five-year research and development program. This program, properly executed, can reasonably be expected to attain the objectives set out in Chapter 7. The salient features of the program are:

- A reasonable balance among the tasks required to regain and maintain energy self-sufficiency:

Task 1.	Conserve energy and energy resources	22%
Task 2.	Increase domestic production of oil and gas	22%
Task 3.	Substitute coal for oil and gas	23%
Task 4.	Validate the nuclear option	24%
Task 5.	Exploit renewable resources (solar, geothermal, fusion, hydroelectric)	9%
		100%

- Massive concentration of effort on short-term objectives: 70% of the total program and 45% of the Federal program go to short-term goals.

- A prudent level of effort directed toward mid-term goals: 23% of the total program and 39% of the Federal program.

- A small but significant share of the program aimed at long-term goals: 7% of the total program, all Federal.

- A conservative estimate of the private research and development contribution that could be forthcoming in response to vigorous and imaginative Federal leadership. (Estimates are based on the 1971 data from the Ford Foundation Energy Policy Project for research and development in the oil, gas, coal-mining, electrical, and electrical supplier industries [$1400 million/year] plus data on

Table 2-1.—RECOMMENDED NATIONAL ENERGY RESEARCH AND DEVELOPMENT PROGRAM, FY 1975-1979

Self-Sufficiency Task	($ Millions) Short-Term Objectives	Mid-Term Objectives	Long-Term Objectives	Total
1. Conserve Energy and Energy Resources				
Federal	1,160	280		1,440
Private	3,200	300		3,500
Subtotal	4,360	580		4,940
2. Increase Domestic Production of Oil and Gas				
Federal	430	30		460
Private	4,300	200		4,500
Subtotal	4,730	230		4,960
3. Substitue Coal for Oil and Gas on a Massive Scale				
Federal	1,690	485		2,175
Private	2,500	500		3,000
Subtotal	4,190	985		5,175
4. Validate the Nuclear Option				
Federal	1,100	2,990		4,090
Private	1,000	250		1,250
Subtotal	2,100	3,240		5,340
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible				
Federal	135	150	1,550	1,835
Private	220	30		250
Subtotal	355	180	1,550	2,085
TOTAL				
Federal	4,515	3,935	1,550	10,000
Private	11,220	1,280		12,500
GRAND TOTAL	15,735	5,215	1,550	22,500

Supporting Programs (incremental Federal funding to present programs)	
Environmental Effects	650
Basic Research	300
Manpower Development	50
	1,000

research expenditures of the automobile industry provided in Congressional hearings [$200 million/year] adjusted for inflationary increases since 1971 and increased expenditures in response to already recognized shortages, making a total of some $2000 million/year in FY 1974. Industry can reasonably be expected to increase research and development spending by at least 25% above current estimates in response to the more than doubled Federal contribution, properly structured Federal policies, and the incentives of higher prices.)

- Allocation of Federal funds among tasks based on the total requirements of each task and on the contributions expected from industry; the Federal share of the total effort varies from slightly under 10% for Task 2 to 88% for Task 5.

- Recommendation of $1000 million for increases in research and development funding of ongoing Federal programs that support energy research and development and energy production.

CONTRIBUTION TO SELF-SUFFICIENCY

Table 2-2 shows the estimated contribution of the recommended program to the goal of regaining self-sufficiency. Entries for 1972 display the composition of energy inputs for that year, including imports of 5.1 million barrels/day of oil equivalent (mostly oil and some natural gas). The Total Energy entries for 1980 and 1985 are based on a projected annual rate of growth in energy consumption of 4.1% from 1972 to 1980 and 3.9% from 1980 to 1985. The conservation entries show the energy savings expected to result from the recommended research and development program. Fuel-source entries for 1980 and 1985 show:

- Contributions expected with programs underway before the President's June 29, 1973, energy initiatives (first column).

- The extra contribution expected from the accelerated research and development efforts included in these initiatives (second column).

- The total contributions expected with the $10 billion program recommended in this report (third column).

The data support the following conclusions:

- Self-sufficiency may be attained by 1985 with the expected payoff of the proposed research and development program. By then, the proposed program should yield the equivalent of:
  (1) 7.0 million barrels/day of energy savings from conservation efforts, and
  (2) 9.0 million barrels/day of increased domestic production.

Table 2-2.—ESTIMATED CONTRIBUTION TO ENERGY INPUTS
(Million Barrels/Day Oil Equivalent)

Energy Source	1972 Actual Inputs	1980 Total with Former Program[1]	1980 Increment from Recommended Program[2]	1980 Total with Recommended Program	1985 Total with Former Program[1]	1985 Increment from Recommended Program[2]	1985 Total with Recommended Programs
Total Energy	34.1	47.0		47.0	57.0		57.0
1. Conservation	—	—	4.7	(4.7)	—	7.0	(7.0)
Production Requirements	34.1	47.0		42.3	57.0		50.0
2. Domestic Production of Oil and Gas	21.4	21.5	0.5	22.0	21.5	5.1	26.6
3. Domestic Coal Production and Conversion	5.9	9.1	0.5	9.6	11.4	2.5	13.9
4. Nuclear	0.3	3.6	0.2	3.8	7.1	0.6	7.7
5. Renewable Resources (Solar, Geothermal, Hydroelectric)	1.4	0.8	0.2	1.0	1.0	0.8	1.8
Imports	5.1	12.0	(6.1)	5.9	16.0	(16.0)	0.0

[1] Contributions expected from policies in effect prior to the President's June 29,1973, energy initiatives, including the energy research and development program contemplated before that initiative. See Appendix B for a comparison of the formerly contemplated program and the program recommended in this report.

[2] See Appendix B for explanation of the methodology used to derive these values.

- By 1980 the recommended program will have decreased the demand for imports by half, to 5.9 million barrels/day of oil equivalent.

- To replace by 1980 the other half of the demand for imports, the Nation must, in addition to conducting the accelerated research and development program:
  (1) reduce energy use by imposing administrative restrictions on consumption, and/or
  (2) take extraordinary measures to stimulate a sharp increase in domestic production.

STRATEGY FOR PROGRAM EXECUTION

The major elements of the strategic approach embodied in the proposed program are:

- Proceed immediately and simultaneously with work on all promising conservation and supply technologies.

- Within each technology, concentrate major effort on the most promising technical approach and keep back-up options advancing at a reasonable pace.

- Pursue most individual research efforts in an accelerated but orderly manner, avoiding the risks of "great leaps forward" that do not materialize; seek, instead, sustained progress toward established objectives.

- Take high risks in a few technologies having very high potential payoffs (e.g., in situ coal gasification and shale retorting and massive fracturing of tight formations containing gas).

- Employ the principle of redundancy: conduct enough parallel efforts to be able to afford failure in some and still attain overall objectives.

- Move toward the capability for self-sufficiency by laying the essential groundwork for a production program based on improved technologies.

A MODEL FOR INTEGRATING RESEARCH AND DEVELOPMENT AND PRODUCTION EFFORTS

One major departure from the conventional approach to research and development is proposed: a Synthetic Fuels Pioneer Program. This effort would begin construction in FY 1975 of a number of commercial-scale plants using existing technologies to produce commercial quantities of synthetic fuels from coal. Program objectives are to:

- Demonstrate the Nation's determination to regain and maintain energy self-sufficiency through an action program that produces commercial quantities of synthetic fuels.

- Lay the technical, engineering, and production groundwork required to support rapid acceleration of synthetic-fuel domestic production if required.

- Adapt proven technologies for synthetic-fuel production to United States conditions.

- Identify by experience the nature and magnitude of the technical, environmental, and economic problems that require priority research and development attention.

- Assign hand-picked teams of scientists, engineers, and technicians to break major bottlenecks to increased productivity and to learn to control and treat adverse environmental effects.

- Establish, based on sustained full-scale operation, technical, engineering, and economic benchmarks for evaluating improvements that result from research and development programs.

- Provide a bridge between the research and development community and the production sector that will facilitate the exchange of information, ideas, and experience gained under full-scale operational conditions.

Major features of the program would be that:

- Federal guarantees of prices or loans under the Defense Production Act or such other authority as may be appropriate would ensure the commercial viability of the plants.
- Exceptions to normal permit requirements would be granted under the authority of emergency energy legislation.
- Defense Production Act or other authority would be used to allocate materials and components on a priority basis to begin construction of these plants in FY 1975 with the objective of having them in full production by the end of FY 1976.
- Plants would be built, owned, and operated by private commercial concerns or consortia; no major Federal construction monies would be required.
- Federal research and development funds in the amount of $355 million would be earmarked for extra construction costs incurred for modifications required to support experimental testing of advanced design components ($100 million) and for research and testing operations ($255 million).
- There would be wide dissemination of the engineering, production, economic, safety, environmental, and other data acquired from operating the plants.
- Plants would be available to the Government for experimentation and evaluation of new techniques, materials, and components on the basis of cost reimbursement to the operator.
- Necessary measures would be taken to contain any adverse environmental impacts within the immediate locale of the plants; this action would provide an ideal experimental base for research into methods of environmental protection and restoration. Industry would bear the costs of containment, and Government would share research costs with industry.

Compared to the total national requirement, the actual production impact of the Synthetic Fuels Pioneer Program would be modest. Its chief benefits would be the knowledge and experience gained that would provide a credible capability for rapid expansion of production if required. This would provide for better integration of the research and development and production programs.

Examples of the kinds of plants that could be included in the program are:

- Pipeline-quality (high-BTU) gas plants using the Lurgi process
- Low-BTU gas plants using the Koppers-Totzek process

- Solvent-refined-coal plants
- Oil from shale plants
- Methanol plant
- Plants to produce hydrogen, ammonia, olefins, diolefins, aromatics, and other petrochemicals.

Details of program implementation remain to be worked out, but discussions with industry representatives indicate that the proposed program could expect an enthusiastic reception from industry. It is strongly recommended as an action program that promises increased production, increased knowledge, and an increasingly realistic and productive interaction between Government and industry based on hard facts derived from commercial-scale operations.

RECOMMENDED FY 1975 BUDGET

Table 2-3 summarizes the FY 1975 Federal budget recommendations by task and displays for comparison purposes corresponding Federal obligations made in FY 1973 and planned for FY 1974. Several features of the program are evident in Table 2-3.

Table 2-3.—FEDERAL ENERGY RESEARCH AND DEVELOPMENT OBLIGATIONS BY MAJOR PROGRAM ELEMENT, FY 1973-1975

Self-Sufficiency Task	($ Millions) Actual FY 73	Planned FY 74	Recommended FY 75	Percent Increase FY 73-75
1. Conserve Energy and Energy Resources	52.8	62.3	166.2	215%
2. Increase Domestic Production of Oil and Gas	20.0	19.5	51.7	159%
3. Substitue Coal for Oil and Gas on a Massive Scale	88.8	167.2	405.0	356%
4. Validate the Nuclear Option	395.8	517.3	731.7	85%
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible	82.8	123.0	217.5	162%
TOTAL	640.2	889.3	1,572.1	146%

- A very substantial acceleration of the upward trend (begun in FY 1974) of Federal energy research and development obligations is proposed. Annual Federal research and development funding would more than double over FY 1973 and would increase by more than three quarters (77%) over FY 1974.

- The largest percentage increase (356%) would be devoted to the use of coal, the Nation's most plentiful energy resource.

- Energy conservation and efforts to use renewable resources would receive major increases.

- The funding increase recommended for oil and gas production reflects the vigorous private research and development programs in that industry and the advanced state of technology that has resulted. Recommended Federal efforts are intended as supplements to selected key areas, including resource assessment, needed to round out an ongoing private program.

- The fission power program would receive a modest increase, much of it aimed at speeding up the availability of electricity from nuclear power plants. This reflects in part the generous level of funding for the nuclear program over past years compared to other programs.

NEED FOR CONTINUING PROGRAM REVIEW

One crucial point deserves emphasis. The FY 1975 budget recommendations are presented with high confidence that they are the right first step in the five-year program. The five-year funding levels are presented with confidence that they represent a sound plan based on what is now known for the five-year period. The actual five-year obligations will be different from those recommended here because the rate at which progress will occur in each program element is unforeseeable.

The entire program should be evaluated at least annually and funds reallocated among surviving programs. If circumstances justify, the $10 billion, *which now appears sufficient*, should be expended earlier than planned, and the total cost of the five-year program should be increased to fund essential research and development. In no case should the planning figures for the later years of the proposed program, or even the total program figures, be either a floor or a ceiling on program funding. Rather, each program should be funded on its merits, accelerated when it succeeds, and terminated or cut back severely when it fails after a reasonable amount of effort. These determinations should be made as part of a total program review, not on a project-by-project basis.

SUMMARY OF FEDERAL PROGRAM ELEMENTS

The following sections contain summaries of the work planned in the principal program elements of each self-sufficiency task. A more detailed budget display for the Federal Energy Research and Development Program is presented in Table 2-4, and subprograms are explained in Appendix A. The major subprograms and funding levels are summarized below in accord with the five major tasks and their short-term, mid-term, and long-term objectives. Tables 2-5 through 2-10, found at the end of the descriptive material, provide summaries for each Fiscal year, FY 1975 through FY 1979, and for the total program of total obligations, operating expenses, equipment obligations, and construction obligations.

Table 2-4.—FEDERAL ENERGY RESEARCH AND DEVELOPMENT OBLIGATIONS BY INDIVIDUAL PROGRAM ELEMENT, FY 1973-1979

	($ Millions)			
Self-Sufficiency Task	Actual FY 73	Planned FY 74	Recommended FY 75	Recommended FY 75-79 Program
1. Conserve Energy and Energy Resources	52.8	62.3	166.2	1,440
Reduced Consumption	12.1	22.3	29.9	210
Increased Efficiency	40.7	40.0	136.3	1,230
2. Increase Domestic Production of Oil and Gas	20.0	19.5	51.7	460
Production	12.8	11.2	31.7	310
Resource Assessment	7.2	8.3	20.0	150
3. Substitute Coal for Oil and Gas on a Massive Scale	88.8	167.2	405	2,175
Mining			45	325
Direct Combustion			30	200
Synthetic Fuels			240	1,270
Common Technology			90	380
4. Validate the Nuclear Option	395.8	517.3	731.7	4,090
Safety, Enrichment, HTGR, and Other	129.7	151.7	216.2	1,245.7
Breeder	266.1	365.6	515.5	2,844.3
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible	82.8	123	217.5	1,835
Fusion	74.8	98.7	145.0	1,450
Solar	4.2	13.2	32.5	200
Geothermal	3.8	11.1	40.0	185
TOTAL	640.2	889.3	1,572.1	10,000
Supporting Programs (incremental Federal funding to present programs)				
Environmental Effect			105.9	650
Basic Research			43.0	300
Manpower Development			5.0	50
			$153.9	$1,000

	($ Millions) FY 75	FY 75-79
Task 1. Conserve Energy and Energy Sources	**$166.2**	**1440.0**
A. Reduced Consumption	**29.9**	**210.0**
1. End-Use Consumption	**19.9**	**150.0**

Major studies will be conducted to determine energy use patterns in building conditioning, industrial processes, transportation systems, integrated utility systems, and patterns across energy sectors. Information gained should provide opportunities for initiating or developing energy-conserving designs, construction, and operating practices.

2. Improved Management	**10.0**	**60.0**

A vigorous effort will be launched to coordinate the activities of the many government departments and agencies that have been compiling data pertaining to the U.S. energy system. Existing systems models will be improved or new models developed, and the data base will be greatly enlarged and kept current. The systems approach and models will be used to assess new technologies and to provide quantitative analysis of alternative energy policies, energy research and development strategies, and energy system configurations.

B. Improved Efficiency	**136.3**	**1230.0**
1. High-Temperature Gas Turbine	**18.3**	**315.0**

In conjunction with conventional steam turbines, combined cycles can be formed that produce greater thermal efficiencies than the steam turbine cycle alone. An open-cycle high-temperature gas turbine will be built to operate in a 100-MW(e) combined-cycle demonstration power plant by 1979. A 2- to 3- MW(e) power plant demonstration unit will be used to assess space heating from power plant waste heat; if successful, the Department of Housing and Urban Development will use such units in model energy-conserving housing developments. A special helium direct-cycle gas turbine facility will be built to develop turbines for use with the high-temperature gas-cooled nuclear reactor.

2. Advanced Cycles, Fuel Cells, and Other Concepts .	**18.0**	**210.0**

Potassium vapor and magnetohydrodynamic "topping" cycles can also form combined cycles for steam turbines. A 30-MW(e) potassium vapor topping unit will be built and operated by 1979 as a pilot plant. Fuel cells of considerable variety will be assessed in pilot plants. The use of wastes as fuels and basic generator research for magnetohydrodynamics are included in this program.

	($ Millions) FY 75	FY 75-79
3. **Advanced Auto Propulsion**	53.0	300.0

Advances in fuel economy and reductions in pollutant emissions using feasible state-of-the-art technologies will be sought and demonstrated for automotive engines. Results will serve to define regulatory standards. Several propulsion and vehicle systems will be evaluated, two of which will be brought to the engineering development phase. Prototype batteries, motors, controls, and power conditioning equipment will be demonstrated by FY 79. Nonpetroleum energy sources will be investigated.

4. **Rail, Bus, Ship, and Air**	20.0	205.0

Two major demonstrations are planned to evaluate integrated bus transit systems in large cities. Intermodal transfer of freight from truck to rail will be investigated. New aircraft and ship designs with low drag characteristics will be evaluated and the feasibility of nuclear-powered commercial ships will be examined.

5. **Energy and Fuel Transportation and Storage**	27.0	200.0

A joint government-industry development program is expected to produce prototype demonstration projects for 1100-kV a-c overhead transmission systems and a 100-MW d-c terminal system by 1979. Four improved types of underground cables will be developed for commercial use in that period. Battery development will continue, with emphasis on the sodium-sulfur and lithium-sulfur designs. A 10-MW pilot model of the more promising design will be built for testing at practical storage levels. The concepts of storing energy in a superconducting magnet or a flywheel will be examined to the point of engineering development. Advanced marine transportation systems will be explored to increase availability and distribution of domestic fuel sources.

The savings in oil equivalent that can be expected from attainment of the objectives of the program in Task 1 are 4.7 million barrels/day of oil by 1980 and 7.0 by 1985.

Task 2. Increase Production of Oil and Gas (including resource assessment)	**$51.7**	**$460.0**
A. **Resource Assessment**	20.0	150.0

New and improved techniques and equipment will be developed and tested to aid the assessment of potentially discoverable resources of fossil and nuclear fuels and supporting elements; to promote their discovery and conversion to reserves; and to determine the quality and usable quantity of coal, oil shale, and tar sands. Data will guide Federal leasing policy and stimulate accelerated exploration by industry.

	($ Millions) FY 75	FY 75-79
B. Secondary and Tertiary Recovery	10.7	70.4

In a joint program with industry, 15 types of reservoirs will be tested with combinations of four methods for secondary and tertiary recovery of residual reserves. Twenty separate experiments will be conducted. Analysis of results is expected to determine economic feasibility for a variety of particular reservoir types.

C. Stimulation of Low Permeability Formations	9.1	96.3

Fluid or hydrofracturing and chemical-explosive fracturing techniques will be tested on a scale not previously tried in an attempt to stimulate low-permeability gas reservoirs that cannot be economically tapped using conventional completion techniques. Seven experiments are planned in three different reservoirs. One further nuclear stimulation demonstration is planned. The program is designed to determine which stimulation technique or combination is most suitable for particular reservoir characteristics.

D. Advanced Drilling	2.6	15.5

Development will be continued on jet drilling techniques and equipment and spark cavitation drilling concepts to increase deep drilling rates. Development of reliable downhole power supplies of up to 100 hp will be pursued. Blowout control and oil-spill cleaning methods will be assessed and improved.

E. Oil-Shale Processing	9.3	127.8

In situ retorting of oil shale will be tested in the Rocky Mountains, using a combination of several different fracturing techniques and retorting conditions. The recovery rates for each combination and the control problems encountered will be analyzed to determine optimal technical design.

The attainment of the objectives of the programs under Task 2 will guarantee the previously projected supply, equivalent to 21.5 million barrels/day of oil, and contribute an **additional** supply, equivalent to 0.5 million barrels/day by 1980 and 5.1 million barrels/day by 1985.

Task 3. Substitute Coal for Oil and Gas	**$405.0**	**$2175.0**
A. Mining	45.0	325.0

New and improved techniques for surface and underground coal and oil-shale mining that would increase productivity and recovery rates and at the same time meet environmental and health standards will be developed and tested in demonstration mines. Integrated mining reclamation methods will be applied to acid Eastern and arid Western surface-mined areas to find optimum techniques for each region.

	($ Millions) FY 75	FY 75-79
B. **Direct Combustion**	30.0	200.0

Pilot, demonstration-scale, and module plants having a pressurized fluid-bed combustion system will be constructed. A companion effort through the demonstration scale will be conducted in atmospheric fluid-bed systems. Combustion modifications will be made in conventional coal- and oil-burning boilers and furnaces to improve the efficiency of combustion under environmentally acceptable conditions.

C. **Synthetic Fuels**	240.0	1270.0
1. **High-BTU Gasification**	35.0	340.0

Four pilot plants for testing advanced technologies will be built. The best features will be incorporated into a demonstration plant by 1979. Knowledge gained from building and operating plants with existing technologies, under the Synthetic Fuels Pioneer Program, should stimulate progress in this area.

2. **Coal Liquefaction**	75.0	375.0

Three pilot plants to test advanced processes for coal liquefaction will be constructed, and a design for a major demonstration plant is expected by 1979.

3. **Low-BTU Gasification**	30.0	200.0

Entrained-bed and fluidized-bed methods for gasifying coal will be tested through demonstration-plant operation in a joint government-industry program of research and development. Three to five other promising approaches to gasification will be tested on a pilot scale.

4. **Synthetic Fuels Pioneer Program**	100.0	355.0

This aggressive new program will immediately begin construction of full-scale commercial plants using existing technologies for producing synthetic fuels from coal. The Lurgi gasification technique and the Fischer-Tropsch liquefaction method will be employed, and a combined process for methanol production will be included. Funding will be derived almost exclusively from private industry, with guaranteed prices or loans as incentives. These will be provided under the Defense Production Act or other authority. Federal research and development funds will be added for investigating processes, testing modifications that appear promising, and disseminating findings. Benchmarks will be established for engineering performance, economic parameters, and environmental aspects of commercial operations. This ambitious production program is expected to accelerate specific research and development efforts related directly to commercial-scale operations and to speed up the implementation of new advances.

	($ Millions) FY 75	FY 75-79
D. Common Technology	90.0	380.0
1. Environmental Control Technology	70.0	260.0

Program emphasis is on the development of advanced flue-gas desulfurization processes that reduce requirements for sludge handling and control and recover elemental sulfur. A major effort will be made to complete and operate several lime/limestone pilot units attached to coal-fired electric generating plants.

The relatively new program directed toward identifying and controlling fine-particulate emissions will be accelerated. Approximately half the funding will be directed to the construction of pilot and demonstration units and instrumentation required to assess the dimensions of this problem and the success of tested processes.

Chemical and mechanical cleaning processes applied to raw coal are expected to remove up to half the organic sulfur. The TRW Meyers process seems promising for such cleaning and will be tested.

Fuel-conversion process-control research and development efforts will identify trace-element emissions that are expected to be present in significant quantities when large volumes of coal are processed. Little is known about their characteristics and control. The program will determine the pollutant effluents and their rates of release and develop processes for control so that the technology can be applied in early commercial-scale plants.

Residues from coal processing will create massive disposal problems that could impact heavily on the environment. Methods for treating, revegetating, or otherwise mitigating harmful or undesirable effects will be sought. In situ coal gasification will be examined as a means of reducing environmental problems.

2. Supporting Research and Development	20.0	120.0

Essential and urgent efforts in developing fittings, pipes, and other hardware; enhancing supplies of hydrogen; and characterizing materials are required to support the main programs in coal research. Coal conversion processes will operate at high temperatures, contain corrosive and abrasive materials, and may include high pressures. To be economic, the processes must run for long periods without overhaul or replacement of major parts. Materials and components that can survive under such conditions must be engineered and tested. In many cases, basic metallurgy problems must be solved. Undoubtedly, new problems will be identified through operation of pilot and demonstration plants and the commercial-scale plants in the Synthetic Fuels Pioneer Program. Hydrogen used in coal conversion processes to enrich the BTU content of the products is produced from the coal or from process water. Current methods are costly or use large quantities of feed stock. Theoretical and empirical efforts will be needed to develop better catalytic methods to produce hydrogen from water.

The attainment of the objectives of the programs under Task 3 will guarantee the previously projected supply, equivalent to 9.1 million barrels/day of oil, and contribute an **additional** supply equivalent to 0.5 million barrels/day by 1980. By 1985 the projected supply of 11.4 million barrels/day will be increased by 2.5 million barrels/day.

	($ Millions) FY 75	FY 75-79
Task 4. Validate the Nuclear Option	**$731.7**	**$4090.0**
A. **Safety, Enrichment, HTGR, Other**	216.2	1245.7
1. **Safety—Reactors and Fuel Handling**	90.6	719.2

Theoretical and experimental investigations will be conducted to determine component failure and accident probabilities for nuclear reactors. Practical results derived from the Loss of Fluid Test Facility (LOFT) will yield data necessary for the design and engineering of safety features and the establishment of regulatory standards.

An engineered waste-storage facility will be constructed, and a pilot facility in bedded salt will be developed to assess the disposal of long-lived radioactive wastes in geologic formations. Ancillary solidification processes will be tested. Methods for elimination of krypton, tritium, and transuranic components of reactor and reprocessing effluents will be tested.

A dry cooling tower to replace liquid cooling will be investigated in Wyoming in a joint government-industry venture. Standardized criteria for nuclear reactor siting will result from an in-depth assessment of the relationship between site characteristics and construction and operating experience, hopefully expediting future installations.

2. **Uranium Enrichment**	64.2	294.2

The search for more-efficient uranium enrichment processes will include development aimed at improving the gaseous diffusion process, demonstrating the commercial feasibility of the gas centrifuge method, and exploring the technical feasibility of isotope separation using lasers. The centrifuge test facility and ancillary facilities will be completed.

	($ Millions) FY 75	FY 75-79
3. **High-Temperature Gas Reactor (HTGR)**	40.0	163.8

The base program for the HTGR will continue the development of components and will review safety features. Reprocessing and refabrication pilot plants will be built to complete needed research and development on the ^{233}U-thorium cycle. This work will enlarge the potential fuel supply by adding the abundant element thorium to uranium as a reactor fuel.

4. **Light Water Self-Sustaining Reactor**	21.4	68.5

An experimental core for this reactor will be tested in the Shippingport facility. Success of this concept will offer a way to make the light-water reactor fuel cycle self-sustaining through conversion to the ^{233}U-thorium cycle.

B. **Breeders**	515.5	2844.3
1. **Liquid Metal Fast Breeder Reactor (LMFBR)** ...	477.0	2556.6

A comprehensive LMFBR technology effort includes support of the Fast Flux Test Facility and support of a 300-MW(e) LMFBR demonstration power plant scheduled for operation in 1980 as a joint government-industry venture. The LMFBR base program includes continued development of fuels and studies of their behavior under different conditions. Engineering and safety aspects will be analyzed at a variety of specialized facilities. These include an advanced fuels laboratory, a steam-generator test facility, a safety test facility, and a transient safety test facility. The suitability of various methods for handling and transporting plutonium will be assessed to generate appropriate standards.

2. **Gas Cooled Fast Reactor (GCFR)**	17.0	140.0

The program for the GCFR will provide required technology on fuel and reactor-core development, physics, and safety. A low level of effort will also be expended on the molten-salt breeder program.

3. **Advanced Technology**	21.5	147.7

This work is planned to develop new breeder fuel and materials that can increase. breeding ratios and power ratings and decrease the conservatism presently required in breeder designs. Neutron cross-section information needed for the design of fast reactors will be developed.

The attainment of the objectives of the programs under Task 4 will guarantee the previously projected supply equivalent to 3.6 million barrels/day of oil, and contribute an **additional** supply equivalent to 0.2 million barrels/day by 1980. By 1985 these programs will guarantee the previously projected supply of 7.1 million barrels/day of oil equivalent and add 0.6 million barrels/day of oil equivalent.

	($ Millions) FY 75	FY 75-79
Task 5. Exploit Renewable Energy Sources	**$217.5**	**$1835.0**
A. Fusion	**145.0**	**1450.0**
1. Magnetic Confinement	135.0	1340.0

Recent successes in fusion-related experiments confirm that the program should move to the next level of orderly experimental development. Computer-analyzed theoretical studies of fusion-relevant plasmas in various confinement configurations will be performed to understand the equilibrium, stability, and transport properties of the plasmas. Facilities will be constructed to test plasma shapes, neutral-beam heating, scaling, and improved confinement. Fusion plasmas create neutron, neutral, charged-particle, and photon environments that have adverse effects on most materials. Basic and applied research will be directed at finding compatible materials that can be fabricated for use in fusion reactors.

2. Laser Fusion	10.0	110.0

This subprogram will extend the theoretical base established in the military-oriented laser fusion program. An experimental demonstration of significant thermonuclear burn and of scientific break even for the method is scheduled.

B. Solar	32.5	200.0
1. Heating and Cooling of Buildings	12.8	50.0

Solar heating and cooling of buildings is entering the pilot-plant stage. Applicability studies, design-criteria development, and component testing will be conducted on a much enlarged scale. Operating pilot systems will be installed in single-family and multifamily dwellings, in agricultural buildings, and in commercial and industrial buildings. This effort could provide the basis for an industry prepared to manufacture solar-energy heating and cooling systems in large quantities. Component development is expected to increase reliability and decrease costs.

2. Solar Thermal Conversion	5.0	35.5

Major emphasis in this subprogram will be placed on the research and development of key subsystems for the optical-transmission central-receiver tower approach. Three system-design efforts will be conducted in parallel. Design, hardware procurement and integration, and testing of a 10-MW(e) pilot plant will be achieved.

		($ Millions) FY 75	FY 75-79
3.	**Wind Energy Conversion**	6.2	31.7

A series of experimental wind generator systems in increasing size and performance capability will be constructed and tested. Multi-unit wind generator systems making up a wind "farm" up to 10 MW(e) will be built late in the program period.

4.	**Ocean Thermal Conversion**	1.9	26.6

Emphasis will be placed on design, production, and testing of system components. Key elements that will require significant adaptation of existing technology include the heat exchanger, deep-water pipe, and overall plant structural design.

5.	**Photovoltaic Conversion**	4.2	35.8

The photovoltaic program will concentrate on the single-crystal silicon approach, with a modest effort on alternative materials and concepts. Major improvements in materials and processes are needed to permit automated production of cells and to accomplish significant cost reductions.

6.	**Bioconversion**	2.4	20.4

The construction and operation of one small-scale pilot plants involves the conversion of wastes into methane and clean fuels. Later in the program period a 10-ton/day urban waste pilot plant will be constructed. Laboratory-scale studies of methods for converting various organic materials, particularly including biomass production, will also be studied.

C.	**Geothermal**	40.0	185.0
1.	**Resource Assessment and Exploration**	9.7	49.2

Activities include the development and field use of new and improved geophysical, geochemical, geologic, and hydrologic instrumentation and techniques to locate and evaluate geothermal resources. Improved prospecting and evaluation methods should allow more confident prediction of the energy potential of individual wells and entire fields. Assurance that a significant (20 to 30 year) supply of geothermal energy is available for plant operation is essential in inducing potential users to invest in power plant development.

2.	**Environmental, Legal, and Institutional Research** ..	3.4	10.9

The effects of potential earth-tremor effects that might result if geothermal resources are extracted will be analyzed. Recirculation methods may maintain in situ conditions and obviate such problems. Minerals, salts, and noxious gases may be prominent by-products of the extraction procedures and must be monitored and eliminated. Technology transfer will be encouraged by cooperative arrangements with industry, and special attention will be given to the institutional, legal, social, and environmental issues bearing on utilization of these novel sources of energy.

	($ Millions) FY 75	FY 75-79
3. **Resource Utilization**	16.9	78.6

Several different types of geothermal resources will be examined: high-temperature low-salinity and high-salinity convective wells, geopressured sedimentary systems, low-temperature convective wells, hot dry rock, and normal geothermal gradients. Four different demonstration plants will be completed and a fifth plant will be started. Each type of resource poses special problems in location and distribution, reservoir analysis, environmental hazards, energy conversion and utilization, and severity and solution time of technical questions involved in bringing the resource to on-line production. Each experimental facility, therefore, will serve as a flexible test bed for research and engineering development, as well as for demonstrations of electrical generation and other uses of geothermal heat. Technology transfer will be encouraged by cooperative arrangements with industry.

4. **Advanced Research and Technology** 10.0 46.3

Major technical problems to be solved are concerned with drilling in hostile geothermal environments, methods of well completion, materials and equipment for extracting corrosive fluids, monitoring and controlling emissions and wastes, and developing practical binary cycles that use low-temperature working fluids.

The attainment of the objectives of the programs under Task 5 will guarantee the previously projected supply, equivalent to 0.8 million barrels/day of oil, and contribute an **additional** supply equivalent to 0.2 million barrels/day by 1980. By 1985 it will guarantee the previously projected supply of 1.0 million barrels/day and add 0.8 million barrels/day of oil equivalent.

SUPPORTING PROGRAMS (Incremental Funding) $153.8 $1000.0

A. **Environment** 105.9 650.0

These programs aim to provide a sound scientific and technical basis for ensuring that potential environmental and health insults will be recognized and effectively controlled as policies to regain and maintain self-sufficiency are implemented.

1. **Pollutant Characterization, Measurement, and Monitoring** 13.3 96.3

The chemical and physical characteristics of by-products associated with each phase of existing and new energy systems from extraction through utilization of the energy will be identified. Methods will be improved or developed for measuring and monitoring ambient and source levels of airborne sulfur oxides, fine particulates, sulfates, krypton, strontium, tritium, waterborne nitrates, and cyanides released by energy systems.

	($ Millions) FY 75	FY 75-79
2. **Environmental Transport Processes**	20.5	110.0

Field studies will be conducted to determine the relationships between emissions of thermal, chemical, and radioactive pollutants and the resulting environmental concentrations by accounting for the pathways of these substances from the energy-system emitter to ultimate fate in the atmosphere or in fresh or marine waters.

3. **Effects: Health, Ecological, Welfare, and Social** ..	69.1	413.7

These studies are intended to strengthen the scientific basis for existing and new air and water quality standards, to define the effects of simultaneous exposure to number of pollutants, and to determine long-term low-level effects of fossil-fuel and radioactive pollutants. Ecological research will assess the impact of coal, oil shale, uranium, and geothermal extraction techniques; of emissions released from energy conversion and reprocessing plants; of waste-heat release and antifouling additives; and of entrainment and impingement in cooling systems. The effects of environmental pollution on the general social welfare will be investigated in studies of public attitudes and values and in physical analyses of artistic works and building materials.

4. **Environmental Assessment and Policy Formulation**	3.0	30.0

Mechanisms will be developed to evaluate the institutional, economic, sociological, and technical implications of environmental impacts and controls and to calculate cost-benefit relationships. Such analyses of alternative energy systems and research and development proposals should permit rational integration of environmental considerations into the energy-policy decision-making process.

B. **Basic Research**	43.0	300.0

These programs are designed to explore phenomena, processes, and techniques in physical, chemical, biological, environmental, and social sciences affecting energy to ensure the development of new basic knowledge. Discoveries of new concepts may revolutionize energy production and utilization.

		($ Millions) FY 75	FY 75-79
1.	**Materials**	8.0	55.0

This work is directed toward understanding the reactions of materials subjected to high temperature, thermal shock, radiation in various forms, and corrosives. Super-conducting materials for very long distance electrical transmission, ion conductance phenomena, and properties of ceramic materials will be investigated.

2.	**Chemical, Physical Engineering**	16.0	110.0

The production of hydrogen and hydrocarbons by thermochemical, photochemical, and biochemical processes from nonfossil sources including water will be stressed. Efforts will be supported to gain understanding of hydrogen storage systems, principally hydrides; of catalysis and the roles of surfaces; of kinetic and heat-transfer processes that affect combustion efficiences; of thermodynamic properties of reactants and carriers important in the energy system; of atmospheric and oceanic mixing; of separation processes; and of methods for detecting the distribution of trace elements and pollutants.

3.	**Biological**	12.0	80.0

Basic knowledge will be acquired to convert organic wastes to usable fuels and to detoxify energy-related wastes. Hydrology and climatology, ecosystem interactions, and environmental geology will receive attention.

4.	**Plasmas**	3.0	20.0

Fundamental research into plasmas and their response to electromagnetic fields and radiation will aid in the development of direct energy conversion systems, orbital solar stations, colliding-beam fusion reactions, and the potential use of kinetic and rotational energies of ocean and planetary movements. Plasma physics is essential, of course, to the entire fusion program.

5.	**Mathematical and Social**	4.0	35.0

Modeling of the entire energy system will require mathematical and computer techniques to handle large and complex technical and socioeconomic data bases in order to understand the effect of technological developments and policy decisions on the energy system. To better understand future energy requirements, social and psychological responses of people, including motivational studies, and national attitude analyses may be helpful. Finally, analysis of the effects of national regulatory policies and international relations on the dynamics of both energy research and development and production will require novel methodologies.

	($ Millions) FY 75	FY 75-79
C. Manpower Development	5.0	50.0

While the potential for redistribution of technical manpower is high, reorientation or retraining will be necessary, and major growth in the longer term must be ensured. The proposed funding level will support a program that would reach over 2000 persons annually, many of them faculty and managers responsible for the education and training of the future manpower pool.

	FY 75	FY 75-79
1. **Faculty Orientation**	1.5	7.5

Institutes, special courses, workshops, conferences, and off-campus appointments for university faculty currently teaching courses in science or technology or conducting research in these fields will be organized and supported.

	FY 75	FY 75-79
2. **Managerial Training and Orientation**	0.5	2.5

Courses and workshops for managers will orient them to particular problems in augmenting the technical manpower forces under their control.

	FY 75	FY 75-79
3. **Student and Postgraduate Support**	1.5	20.0

Support will be directed toward undergraduate and postgraduate students pursuing science and engineering. Traineeships, scholarships, research stipends, and postdoctoral fellowships will be required in energy and energy-related areas.

	FY 75	FY 75-79
4. **Industry/Labor Manpower Development Program**	1.5	20.0

A cooperative program with national laboratories and contractors will lead to retraining and reorientation of technical workers whose skills are presently inappropriate to specific needs in energy-related industries. Government funding will support external educational assistance, manpower increases needed to conduct training, and training period stipends.

The incremental funding provided in these areas of environmental research, multidirectional research, and manpower development represents vital support for the near and longer term energy research and development and implementation efforts. Additional program detail is in Appendix A.

Table 2-5.—SUMMARY SCHEDULE OF FEDERAL ENERGY RESEARCH AND DEVELOPMENT PROGRAMS, FY 1975-1979, BY TASK
($ Millions)

Self-Sufficiency Task	FY 73	FY 74	FY 75-79 Energy Research and Development Programs FY 75	FY 76	FY 77	FY 78	FY 79	FY 75-79	FY 75-79 Agency Projections
1. Conserve Energy and Energy Resources									
Reduced Consumption	12.1	22.3	29.9	43.7	51.5	44.4	40.5	210.0	15.0
Increased Efficiency	40.7	40.0	136.3	223.4	267.0	287.8	315.5	1230.0	80.0
Subtotal	52.8	62.3	166.2	267.1	318.5	332.2	356.0	1440.0	95.0
2. Increase Domestic Production of Oil and Gas									
Production	12.8	11.2	31.7	89.1	79.5	59.5	50.2	310.0	50.0
Resource Assessment	7.2	8.3	20.0	23.0	29.5	37.5	40.0	150.0	40.0
Subtotal	20.0	19.5	51.7	112.1	109.0	97.0	90.2	460.0	90.0
3. Substitute Coal for Oil and Gas on a Massive Scale									
Mining			45.0	57.0	64.0	77.0	82.0	325.0	
Direct Combustion			30.0	35.0	40.0	44.0	51.0	200.0	
High-BTU Gasification			35.0	75.0	92.0	81.0	57.0	340.0	
Coal Liquefaction			75.0	75.0	75.0	75.0	75.0	375.0	
Low-BTU Gasification			30.0	37.0	42.0	48.0	43.0	200.0	
Synthetic Fuels—Industry Pioneering			100.0	100.0	55.0	50.0	50.0	355.0	
Environmental Control Technology			70.0	50.0	42.0	45.0	53.0	260.0	
Supporting Research and Development			20.0	22.0	24.0	27.0	27.0	120.0	
Subtotal	88.8	167.2	405.0	451.0	434.0	447.0	438.0	2,175.0	842.0
4. Validate the Nuclear Option									
Safety and Other	42.7	51.7	90.6	125.6	143.0	170.5	189.5	719.2	609.9
Uranium Enrichment	50.3	56.8	64.2	54.8	57.4	58.4	59.4	294.2	284.5
High Temperature Gas Reactor	7.2	14.2	40.0	44.7	24.2	26.9	28.0	163.8	128.6
Light Water Self-Sustaining Reactor	29.5	29.0	21.4	17.7	9.8	9.8	9.8	68.5	68.5
Liquid Metal Fast Breeder Reactor	253.8	356.8	477.0	538.6	510.8	524.2	506.0	2,556.6	2,470.6
Gas Cooled Fast Breeder	1.0	1.0	17.0	23.0	29.0	33.0	38.0	140.0	27.0
Advanced Technology	11.3	7.8	21.5	24.5	30.5	34.0	37.2	147.7	83.2
Subtotal	395.8	517.3	731.7	828.9	804.7	856.8	867.9	4,090.0	3,672.3
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible									
Fusion—Confinement	39.7	55.8	135.0	230.0	261.0	338.0	376.0	1,340.0	1,132.0
Fusion—Laser	35.1	42.9	10.0	20.0	25.0	25.0	30.0	110.0	
Solar	4.2	13.2	32.5	39.9	41.4	42.2	44.0	200.0	80.0
Geothermal	3.8	11.1	40.0	41.0	40.8	35.7	27.5	185.0	20.0
Subtotal	82.8	123.0	217.5	330.9	368.2	440.9	477.5	1,835.0	1,232.0
TOTAL	640.2	889.3	1,572.1	1,990.0	2,034.4	2,173.9	2,229.6	10,000.0	5,931.3

Table 2-6.—SUMMARY SCHEDULE OF FEDERAL ENERGY RESEARCH AND DEVELOPMENT PROGRAMS, FY 1975-1979
($ Millions)

	FY 75-79 Energy Research and Development Programs FY 75	FY 76	FY 77	FY 78	FY 79	FY 75-79
Operating Expenses	1,062.1	1,311.0	1,451.4	1,519.3	1,618.8	6,962.6
Equipment	160.7	233.4	211.3	242.4	250.3	1,098.1
Construction	349.3	445.6	371.7	412.2	360.5	1,939.3
TOTAL	1,572.1	1,990.0	2,034.4	2,173.9	2,229.6	10,000.0

Table 2-7.—OPERATING EXPENSES FOR FEDERAL ENERGY RESEARCH AND DEVELOPMENT PROGRAMS, FY 1975-1979
($ Millions)

Self-Sufficiency Task	FY 75-79 Energy Research and Development Programs					
	FY 75	FY 76	FY 77	FY 78	FY 79	FY 75-79
1. Conserve Energy and Energy Resources						
Reduced Consumption	26.6	34.3	38.2	36.6	35.2	170.9
Increased Efficiency	112.2	155.5	178.8	190.2	216.0	852.7
Subtotal	138.8	189.8	217.0	226.8	251.2	1,023.6
2. Increase Domestic Production of Oil and Gas						
Production	26.0	70.2	67.6	51.6	45.9	261.3
Resource Assessment	14.8	19.8	24.7	31.5	33.7	124.5
Subtotal	40.8	90.0	92.3	83.1	79.6	385.8
3. Substitute Coal for Oil and Gas on a Massive Scale						
Mining	28.5	34.5	36.0	41.5	45.5	186.0
Direct Combustion	12.8	18.4	10.9	12.4	13.3	67.8
High-BTU Gasification	12.5	24.0	47.0	49.0	53.0	185.5
Coal Liquefaction	52.0	38.0	38.0	40.0	45.0	213.0
Low-BTU Gasification	3.8	5.0	7.0	10.0	14.0	39.8
Synthetic Fuels—Industry Pioneering	46.0	45.5	50.0	44.5	44.0	230.0
Environmental Control Technology	42.0	25.0	22.0	30.0	47.0	166.0
Supporting Research and Development	18.0	20.0	21.5	24.0	24.0	107.5
Subtotal	215.6	210.4	232.4	251.4	285.8	1,195.6
4. Validate the Nuclear Option						
Safety and Other	74.8	88.5	104.6	117.6	130.6	516.1
Uranium Enrichment	44.1	47.0	48.0	49.0	50.0	238.1
High-Temperature Gas Reactor	20.8	21.3	22.8	25.3	26.3	116.5
Light Water Self-Sustaining Reactor	21.1	17.4	9.3	9.3	9.3	66.4
Liquid Metal Fast Breeder Reactor	303.6	361.3	380.4	390.6	382.3	1,818.2
Gas Cooled Fast Breeder	13.0	21.4	26.8	30.2	34.6	126.0
Advanced Technology	21.1	23.8	29.2	32.4	35.6	142.1
Subtotal	498.5	580.7	621.1	654.4	668.7	3,023.4
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible						
Fusion—Confinement	112.0	170.0	215.0	235.0	265.0	997.0
Fusion—Laser	8.0	17.0	22.0	22.0	27.0	96.0
Solar	21.2	22.4	21.5	19.3	19.9	104.3
Geothermal	27.2	30.7	30.1	27.3	21.6	136.9
Subtotal	168.4	240.1	288.6	303.6	333.5	1,334.2
TOTAL	1,062.1	1,311.0	1,451.4	1,519.3	1,618.8	6,962.6

Table 2-8.—EQUIPMENT OBLIGATIONS FOR FEDERAL ENERGY RESEARCH AND DEVELOPMENT PROGRAMS, FY 1975-1979
($ Millions)

	FY 75-79 Energy Research and Development Programs					
Self-Sufficiency Task	FY 75	FY 76	FY 77	FY 78	FY 79	FY 75-79
1. Conserve Energy and Energy Resources						
Reduced Consumption	2.7	6.2	8.7	4.2	3.5	25.3
Increased Efficiency	20.5	41.2	49.0	46.2	47.2	204.1
Subtotal	23.2	47.4	57.7	50.4	50.7	229.4
2. Increase Domestic Production of Oil and Gas						
Production	5.7	18.9	11.9	7.9	4.3	48.7
Resource Assessment	2.7	3.2	4.3	6.0	6.3	22.5
Subtotal	8.4	22.1	16.2	13.9	10.6	71.2
3. Substitute Coal for Oil and Gas on a Massive Scale						
Mining	13.0	16.0	18.5	22.5	30.0	100.0
Direct Combustion	5.1	6.6	9.4	10.2	15.1	46.4
High-BTU Gasification	1.5	1.0				2.5
Coal Liquefaction	5.0	7.0	5.0	6.0	10.0	33.0
Low-BTU Gasification	1.0	1.7	2.0		1.0	5.7
Synthetic Fuels—Industry Pioneering	4.0	4.5	5.0	5.5	6.0	25.0
Environmental Control Technology	10.0	5.0	4.0	4.0	5.0	28.0
Supporting Research and Development	2.0	2.0	2.5	3.0	3.0	12.5
Subtotal	41.6	43.8	46.4	51.2	70.1	253.1
4. Validate the Nuclear Option	13.8	7.1	8.4	8.9	8.9	47.1
Safety and Other	5.1	4.8	6.4	6.4	6.4	29.1
Uranium Enrichment						
High-Temperature Gas Reactor	1.2	1.4	1.4	1.6	1.7	7.3
Light Water Self-Sustaining Reactor	0.3	0.3	0.5	0.5	0.5	2.1
Liquid Metal Fast Breeder Reactor	23.4	33.3	27.4	29.6	40.7	154.4
Gas Cooled Fast Breeder	1.0	1.6	2.2	2.8	3.4	11.0
Advanced Technology	0.4	0.7	1.3	1.6	1.6	5.6
Subtotal	45.2	49.2	47.6	51.4	63.2	256.6
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible						
Fusion—Confinement	23.0	49.0	24.0	58.0	35.0	189.0
Fusion—Laser	2.0	3.0	3.0	3.0	3.0	14.0
Solar	8.3	11.6	11.0	10.1	14.6	55.6
Geothermal	9.0	7.3	5.4	4.4	3.1	29.2
Subtotal	42.3	70.9	43.4	75.5	55.7	287.8
TOTAL	160.7	233.4	211.3	242.4	250.3	1,098.1

Table 2-9.—CONSTRUCTION OBLIGATIONS FOR FEDERAL ENERGY RESEARCH AND DEVELOPMENT PROGRAMS, FY 1975-1979
($ Millions)

	FY 75-79 Energy Research and Development Programs					
Self-Sufficiency Task	FY 75	FY 76	FY 77	FY 78	FY 79	FY 75-79
1. Conserve Energy and Energy Resources						
Reduced Consumption	0.6	3.2	4.6	3.6	1.8	13.8
Increased Efficiency	3.6	26.7	39.2	51.4	52.3	173.2
Subtotal	4.2	29.9	43.8	55.0	54.1	187.0
2. Increase Domestic Production of Oil and Gas						
Production						
Resource Assessment	2.5		0.5			3.0
Subtotal	2.5		0.5			3.0
3. Substitute Coal for Oil and Gas on a Massive Scale						
Mining	3.5	6.5	9.5	13.0	6.5	39.0
Direct Combustion	12.1	10.0	19.7	21.4	22.6	85.8
High-BTU Gasification	21.0	50.0	45.0	32.0	4.0	152.0
Coal Liquefaction	18.0	30.0	32.0	29.0	20.0	129.0
Low-BTU Gasification	25.2	30.3	33.0	38.0	28.0	154.5
Synthetic Fuels—Industry Pioneering	50.0	50.0				100.0
Environmental Control Technology	18.0	20.0	16.0	11.0	1.0	66.0
Supporting Research and Development						
Subtotal	147.8	196.8	155.2	144.4	82.1	726.3
4. Validate the Nuclear Option						
Safety and Other	2.0	30.0	30.0	44.0	50.0	156.0
Uranium Enrichment	15.0	3.0	3.0	3.0	3.0	27.0
High-Temperature Gas Reactor	18.0	22.0				40.0
Light Water Self-Sustaining Reactor						
Liquid Metal Fast Breeder Reactor	150.0	144.0	103.0	104.0	83.0	584.0
Gas Cooled Fast Breeder	3.0					3.0
Advanced Technology						
Subtotal	188.0	199.0	136.0	151.0	136.0	810.0
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible						
Fusion—Confinement		11.0	22.0	45.0	76.0	154.0
Fusion—Laser						
Solar	3.0	5.9	8.9	12.8	9.5	40.1
Geothermal	3.8	3.0	5.3	4.0	2.8	18.9
Subtotal	6.8	19.9	36.2	61.8	88.3	213.0
TOTAL	349.3	445.6	371.7	412.2	360.5	1,939.3

Table 2-10.—OPERATING EXPENSES AND EQUIPMENT AND CONSTRUCTION OBLIGATIONS FOR FEDERAL SUPPORTING RESEARCH AND DEVELOPMENT PROGRAMS, FY 1975-1979
($ Millions)

	FY 75-79 Energy Research and Development Programs					
	FY 75	FY 76	FY 77	FY 78	FY 79	FY 75-79
Operating Expenses						
Environmental Research	88.5	98.5	111.0	125.7	137.1	560.8
Basic Research	39.0	52.1	59.6	60.7	59.2	270.6
Manpower Development	5.0	9.0	12.5	12.3	11.2	50.0
Subtotal	132.5	159.6	183.1	198.7	207.5	881.4
Equipment Obligations						
Environmental Research	5.9	9.9	10.5	18.7	6.2	51.2
Basic Research	4.0	5.9	6.4	6.3	6.8	29.4
Manpower Development						
Subtotal	9.9	15.8	16.9	25.0	13.0	80.6
Construction Obligations						
Environmental Research	11.5	13.5	7.0	3.0	3.0	38.0
Basic Research						
Manpower Development						
Subtotal	11.5	13.5	7.0	3.0	3.0	38.0
TOTAL	153.9	188.9	207.0	226.7	223.5	1,000.0

3

Energy Supply and Demand

The goals of the energy research and development program can be deduced from a brief analysis of the energy situation which sets out:

- Recent developments.
- The present situation.
- Desired future conditions.
- Measures required to attain those conditions.
- Research and development needs to make those measures possible.

RECENT DEVELOPMENTS

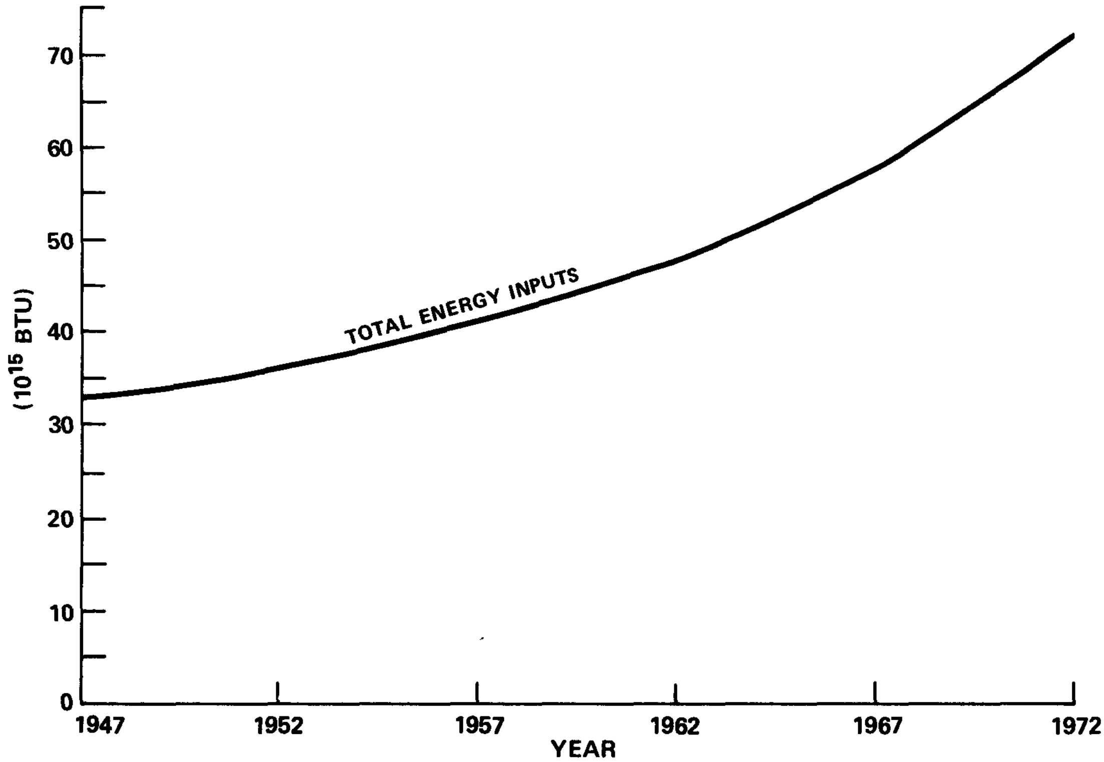
This Nation has until recently been blessed with abundant domestic supplies of readily accessible fuels. As a result, energy has been cheap relative to other commodities. Even today, United States energy costs relative to those of other commodities are less than in any other industrialized country, and these costs have declined over the last several years. In 1972 energy costs amounted to some 4% of the United States gross national product compared to 8 to 12% for most nations in Western Europe.

Until quite recently, energy has been produced from domestic resources in ways that seemed environmentally acceptable. Under these conditions United States consumption of energy has expanded enormously and at increasingly rapid rates, as shown in Figure 3-1. In 1972, with **one-sixteenth** of the world's population, the United States consumed more than **one-third** of the world's total energy production. The trend in absolute level of energy consumption is upward, although the United States share of total world consumption can be expected to fall as development proceeds in other countries.

About 25 years ago, major trends caused by market forces began to influence the energy system. The cleanest and most convenient fuels, natural gas and petroleum, were also the cheapest; so they began to displace coal. As

Figure 3-1

GROWTH IN UNITED STATES TOTAL ENERGY CONSUMPTION, 1947-1972



	Year					
	1947	1952	1957	1962	1967	1972
Total Energy Inputs (10^{12} BTU)	33,035	36,458	41,706	47,422	58,265	72,091
Five-Year Average Annual Rate of Growth (%)[1]		1.99	2.73	2.60	4.20	4.35

[1] These are average annual growth rates for each successive five-year period (e.g., 1947-1952, 1952-1957).

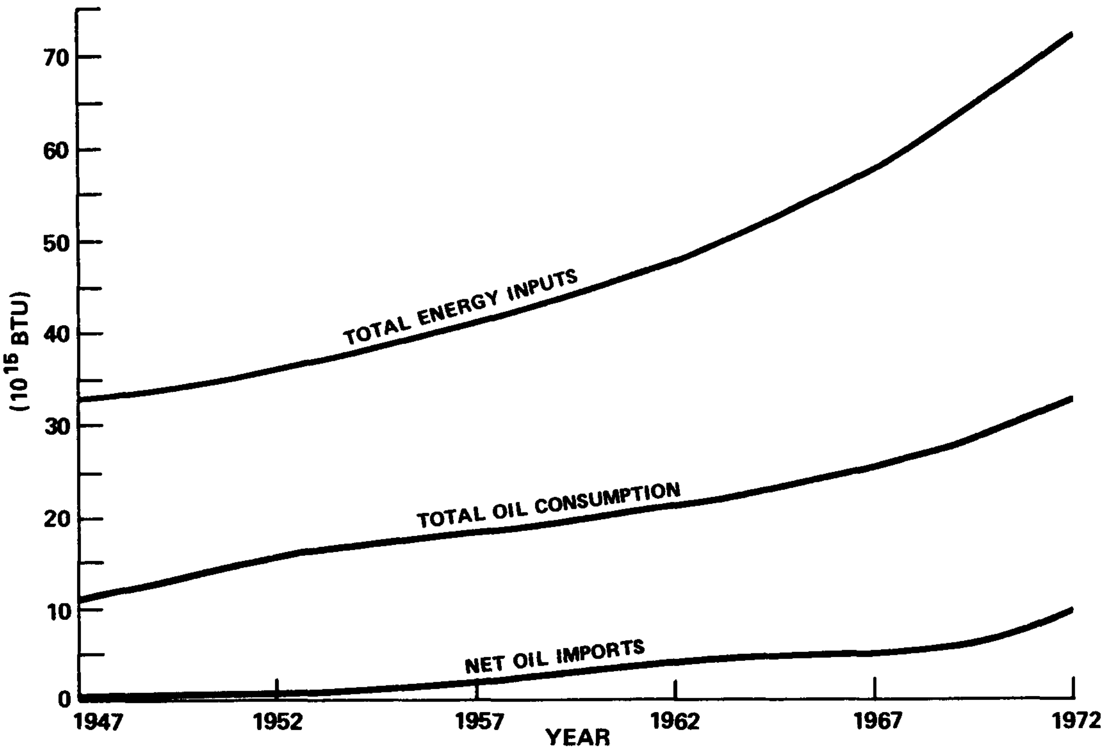
SOURCE: "UNITED STATES ENERGY THROUGH THE YEAR 2000," DEPARTMENT OF INTERIOR, 1972

consumption of petroleum began to outstrip domestic production rates, the United States began to import foreign oil because it was cheaper than domestic oil.

Although the Nation has been importing crude oil and refined products since the late 1940s, it was a net exporter of energy until 1958. Until then the energy value of coal exports exceeded that of oil imports. Figure 3-2 traces the growing contribution of oil and oil imports to our energy supplies. In 1957 the net imports of petroleum and petroleum products were 1

Figure 3-2

UNITED STATES OIL CONSUMPTION AND OIL IMPORTS, 1947-1972



	Year 1947	1952	1957	1962	1967	1972
Energy Inputs (10^{12} BTU)						
Total Energy Inputs	33,035	36,458	41,706	47,422	58,265	72,091
Total Oil Consumption	11,367	15,334	18,570	21,267	25,335	32,812
Net Oil Imports	10	1,186	2,253	4,222	4,841	9,588
Oil Imports as a Percentage of:						
Total Oil Consumption (%)		7.7	12.1	19.9	19.1	29.2
Total Energy (%)		3.3	5.4	8.9	8.3	13.3
Oil Consumption as a Percentage of Total Energy (%)	34.4	42.1	44.5	44.8	43.5	45.5

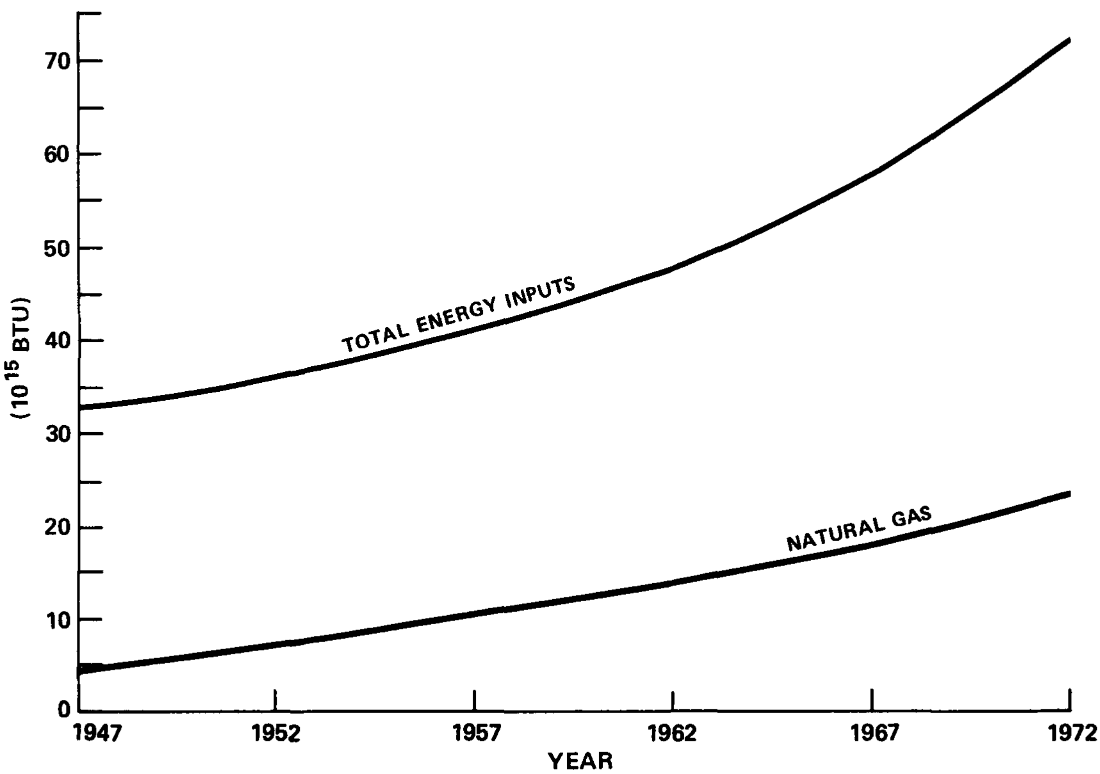
SOURCE: "UNITED STATES ENERGY THROUGH THE YEAR 2000," DEPARTMENT OF INTERIOR, 1972

million barrels/day. This represented some 12% of United States oil consumption, but only 5% of United States energy consumption at the time. The import levels grew slowly at first then rapidly in recent years. During the first half of 1973, the United States imported over 6 million barrels/day of oil, which represented about 33% of its oil consumption and about 17% of its energy consumption in that period.

Late in this same period, the rate of exploration for natural gas declined for two reasons. First, natural gas is often found in conjunction with or while seeking oil; however, with the discovery of cheap foreign oil sources, most oil exploration activity moved abroad. Second, a ceiling was imposed on the wellhead price of gas. As drilling costs rose and finding rates declined, the ceiling price reduced the incentive to drill for gas in the United States. With the price of gas lower than it would have been on the free market, gas consumption grew at an even faster rate than total energy consumption, increasing from 13% of total energy consumed in 1947 to 32% in 1972, as shown in Figure 3-3. Natural gas had all the advantages; it was cheaper,

Figure 3-3

UNITED STATES NATURAL GAS CONSUMPTION, 1947-1972



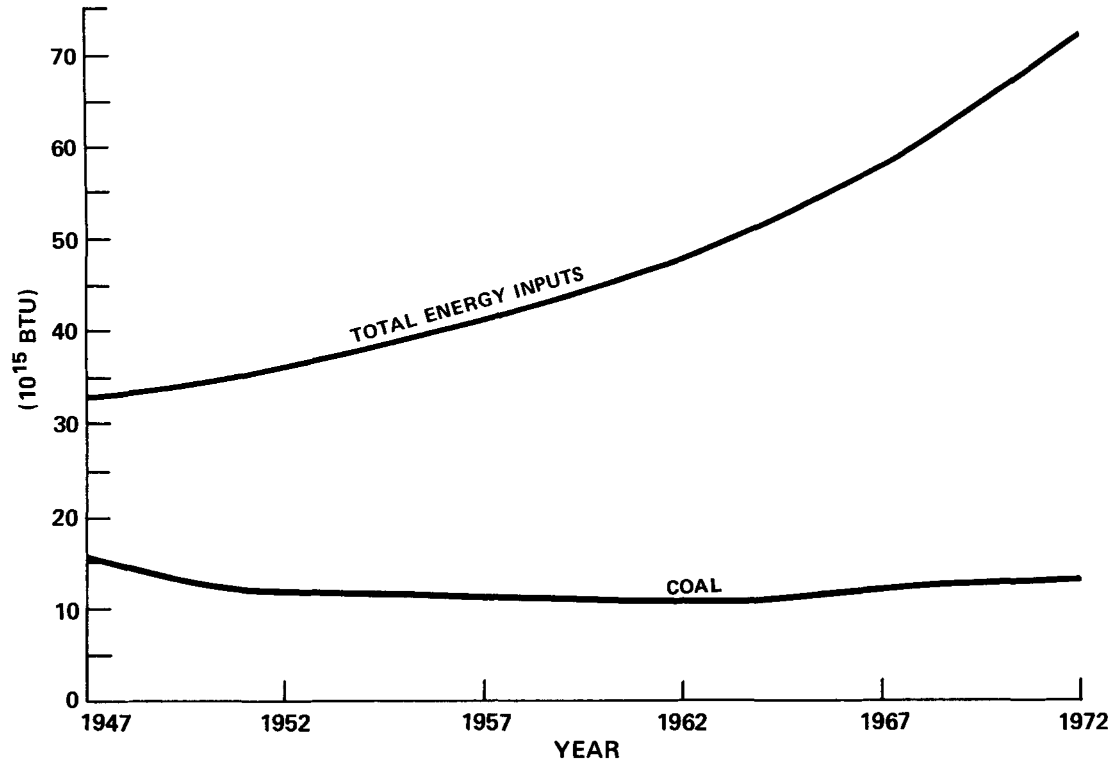
	Year					
	1947	1952	1957	1962	1967	1972
Energy Inputs (10^{12} BTU)						
Total Energy Inputs	33,035	36,458	41,706	47,422	58,265	72,091
Natural Gas	4,518	7,760	10,416	14,121	18,250	23,308
Natural Gas as a Percentage of Total Energy (%)	13.7	21.3	25.0	29.8	31.3	32.3

SOURCE: "UNITED STATES ENERGY THROUGH THE YEAR 2000," DEPARTMENT OF INTERIOR, 1972 cleaner, and more convenient than other fuels, and its supply appeared to be ensured.

The gains in oil and gas use were made at the expense of coal. The share of coal in supplying total United States energy needs fell from 48% in 1947 to 17% in 1972. Details are shown in Figure 3-4.

More recently, environmental concerns led to the passage of the Clean Air Amendments of 1970 (P.L. 91-604), which set ambient air quality standards to be attained and maintained. Meeting these standards required

Figure 3-4
UNITED STATES COAL CONSUMPTION, 1947-1972



	1947	1952	1957	1962	1967	1972
Energy Inputs (10^{12} BTU)						
Total Energy Inputs	33,035	36,458	41,706	47,422	58,265	72,091
Coal	15, 824	11,868	11,168	10,189	12,256	12,428
Coal as a Percentage of Total Energy (%)	47.9	32.6	26.8	21.5	21.0	17.2

SOURCE: "UNITED STATES ENERGY THROUGH THE YEAR 2000," DEPARTMENT OF INTERIOR, 1972 significant reductions in emissions of sulfur oxides from the stacks of most coal-burning processes. At that time most coal used had a high sulfur content; so the new emission standards accelerated sharply the shift from coal to oil and gas.

So long as supplies of oil imports seemed to be ensured, there was little cause for concern about domestic self-sufficiency. United States companies owned controlling interests in the firms producing and delivering foreign oil, and there seemed to be no practical limits on foreign production capacity. That much of the refining was done abroad and products were imported was no cause for concern so long as a continuous flow of fuel was reasonably ensured. Failure to use cheap foreign oil would have caused an unnecessary rise in the cost of energy at home and slower progress toward meeting desired environmental standards. The result has been an increasing dependence on oil imports.

THE PRESENT SITUATION

Suddenly a new set of conditions exists. A major portion of foreign oil supplies has been interrupted, and there are no readily available alternate sources for the quantity required. Consequently the United States faces major economic dislocations and unwelcome changes in the way its people live, work, and play.

Energy policy makers must choose among some undesirable alternatives to adjust to these new conditions. To absorb the sudden reduction in oil imports, the United States will pay a high price in some combination of dollars, environmental impacts, and social dislocations. The exact amounts of each required to balance energy supply and demand are determined by the state of energy production and use technology and by the behavior patterns of the producers and consumers of energy. The nature of the present emergency is clear; its dimensions are less so.

HOW FAR TO SELF-SUFFICIENCY?

The specifics of the energy supply and demand situation as of 1970 are displayed in Figure 3-5. Forecasts of the demand for energy and the contribution of the various fuel sources to meet that demand are based largely on projections of trends dictated mostly by economic considerations. A consensus of estimates of the 1980 energy situation past trends continued is shown in Figure 3-6. That consensus projected oil imports of 10 million barrels/day and gas imports equivalent to almost 2 million more barrels/day of oil. Clearly the energy situation in 1980 will have to differ by the equivalent of some 12 million barrels/day of oil from previous estimates if the Nation is to be self-sufficient by then.

In the face of current and projected shortages, the price of energy relative to that of other commodities will rise sharply. This rise will generate economic incentives both to conserve energy and to increase domestic supplies. The extent of these changes depends on:

- How fast the price rises.
- How high it rises.
- How long it maintains given levels.
- What consumers and producers expect to happen to future prices.
- Their responses over time to the pattern of actual and expected price increases.

None of these quantities is known.

One thing is clear beyond question: the Nation must exert every effort toward reducing the rate of growth in energy demand and increasing domestic energy supplies. The projected shortage of approximately 12 million barrels/day of oil equivalent by 1980 (Figure 3-6) did **not** incorporate the effects of the sharp rise in the price of energy expected in the near future.

Because the rise in energy cost will, of itself, restrain the growth of energy demand to some extent, the self-sufficiency target for increased production by 1980 will be something less than 12 million barrels/day of oil equivalent. How much less is not known with any confidence; one high-priority energy research and development objective must be to develop better methods for predicting that quantity.

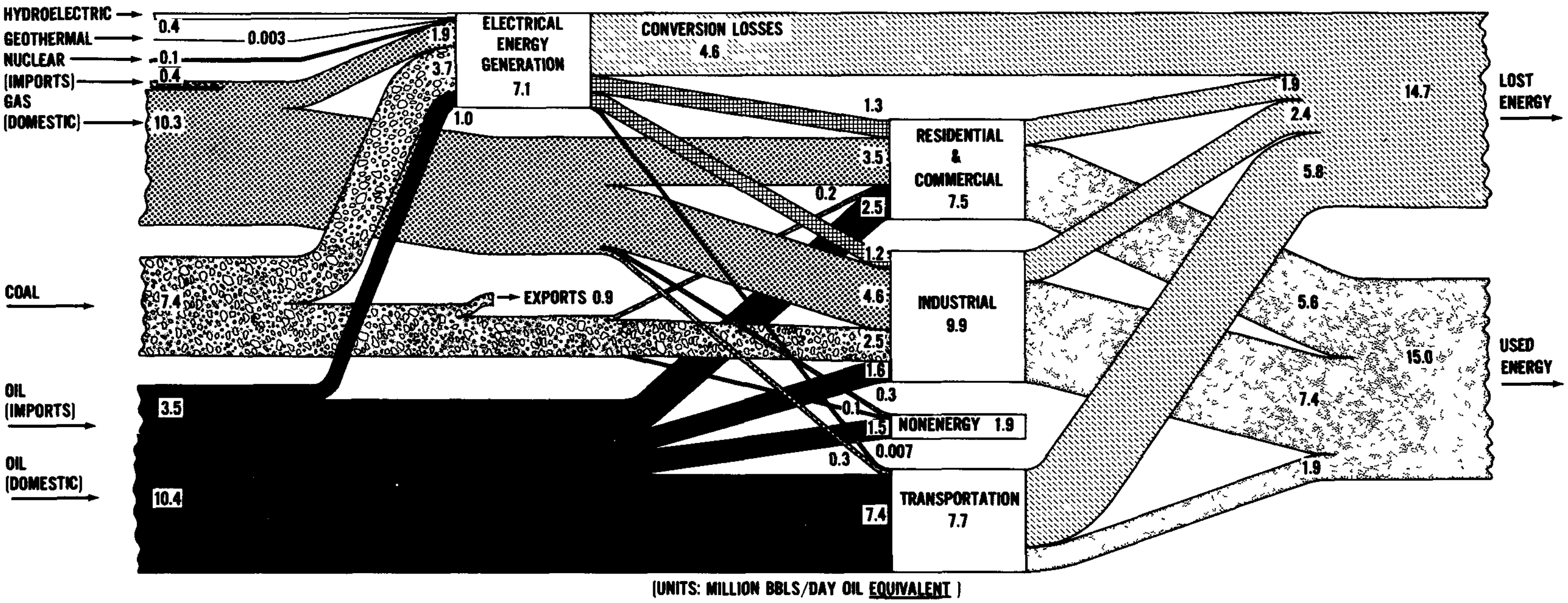
Projections of the effect of price increases on moderating energy demand were developed as follows. If the real cost of energy doubles throughout the economy by 1980, an optimistic prediction would be to expect a 10% reduction in total energy demand in response to a doubling of the relative price of energy. This means that domestic supplies would still have to increase by the equivalent of something like 7.3 million barrels/day of oil if administrative rationing measures are to be avoided. An even more optimistic prediction—that a doubling of the relative price of energy would reduce the demand by 15%—would still require an increase in domestic production of about 5 million barrels/day of oil equivalent.

Clearly a major part of the burden of attaining self-sufficiency without controls must fall on increased supplies. For the United States to attain energy self-sufficiency by 1980, even if present energy costs are doubled, domestic supplies will have to increase by the equivalent of 5 to 7 million barrels/day of oil.

But the requirement to regain self-sufficiency does not stem from the present oil embargo alone. Figure 3-7 shows the expected long-range development of the Nation's energy future before the requirement to regain and sustain domestic self-sufficiency. Although estimates this far in the future are imprecise, this figure does show the relative magnitudes of the major transformations that were projected for the energy system. The huge bulge in projected imports is the most striking characteristic. The balance-of-payment implications of this level of imports in the face of competing claims from other users and restricted production rates by producing countries are reason enough in themselves to begin now to move

Figure 3-5
UNITED STATES ENERGY FLOW PATTERN
ACTUAL – 1970

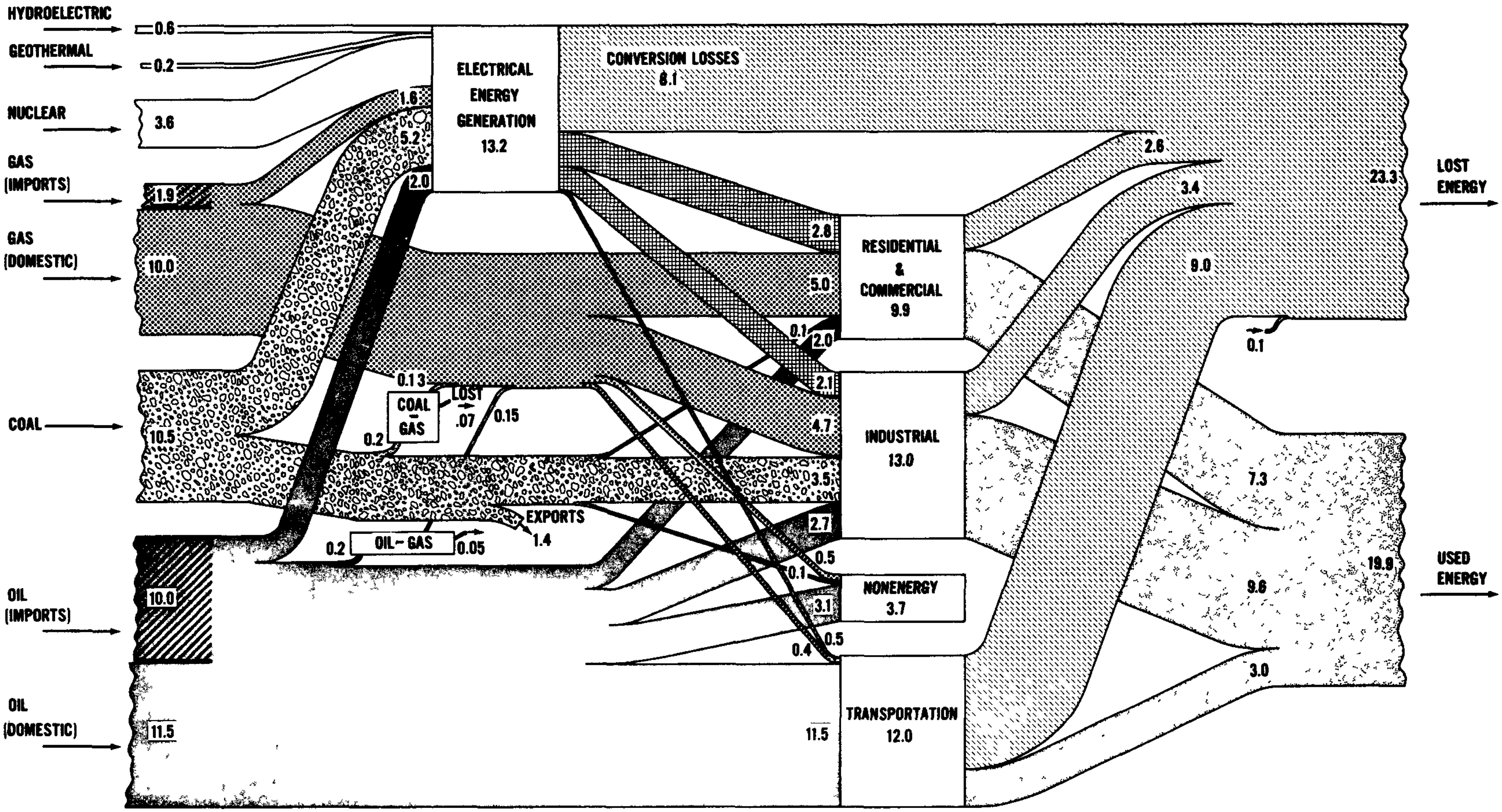
1970



SOURCE: "UNDERSTANDING THE 'NATIONAL ENERGY DILEMMA'." JCAE, 1973

1980

Figure 3-6
UNITED STATES ENERGY FLOW PATTERN
PROJECTED – 1980



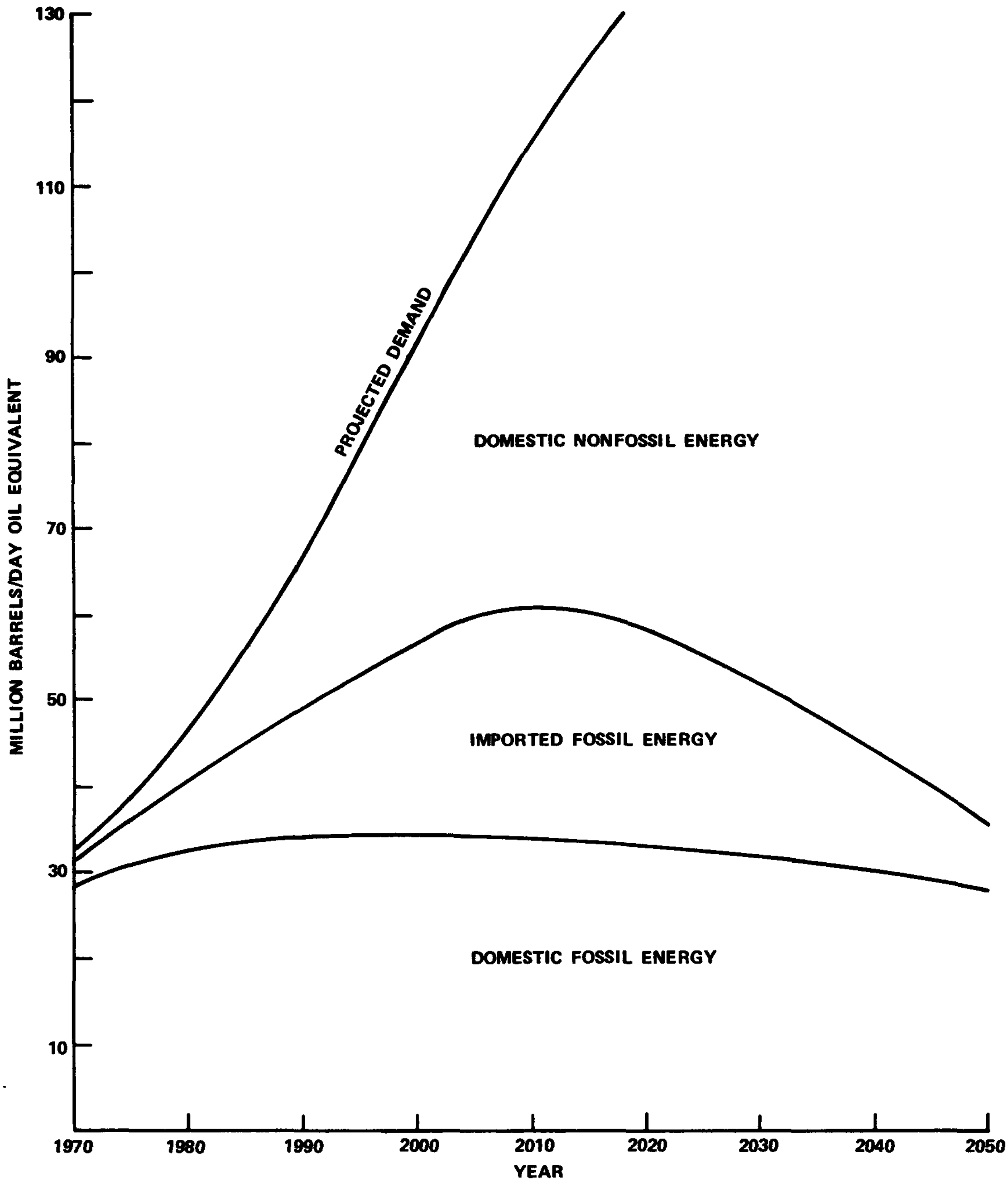
(UNITS: MILLION BBLS/DAY OIL EQUIVALENT)

SOURCE: "UNDERSTANDING THE 'NATIONAL ENERGY DILEMMA'," JCAE, 1973 toward self-sufficiency. The present crisis has simply accelerated the time of a general awareness of the problem; it may well turn out to have been a blessing in disguise. Figure 3-7 also helps convey the magnitude of the job to be done in sustaining domestic self-sufficiency for any period after it is attained by 1980.

Figure 3-8, a modification of Figure 3-7, displays an estimate of the changes that will have to be made by 1980 in domestic energy production and consumption to regain self-sufficiency by 1980. It shows the dramatic increase in domestic fossil-fuel production that will be required, even assuming a 10% decline in the previously projected levels of energy demand. Such a fundamental change over the next seven years will be possible only with a vigorous energy research and development program and an equally vigorous production program that supports the early and widespread application of technological advances throughout the economy. The clear message in Figures 3-7 and 3-8 is that major transformations of the energy system are going to be required and the Nation must get started on them **now**.

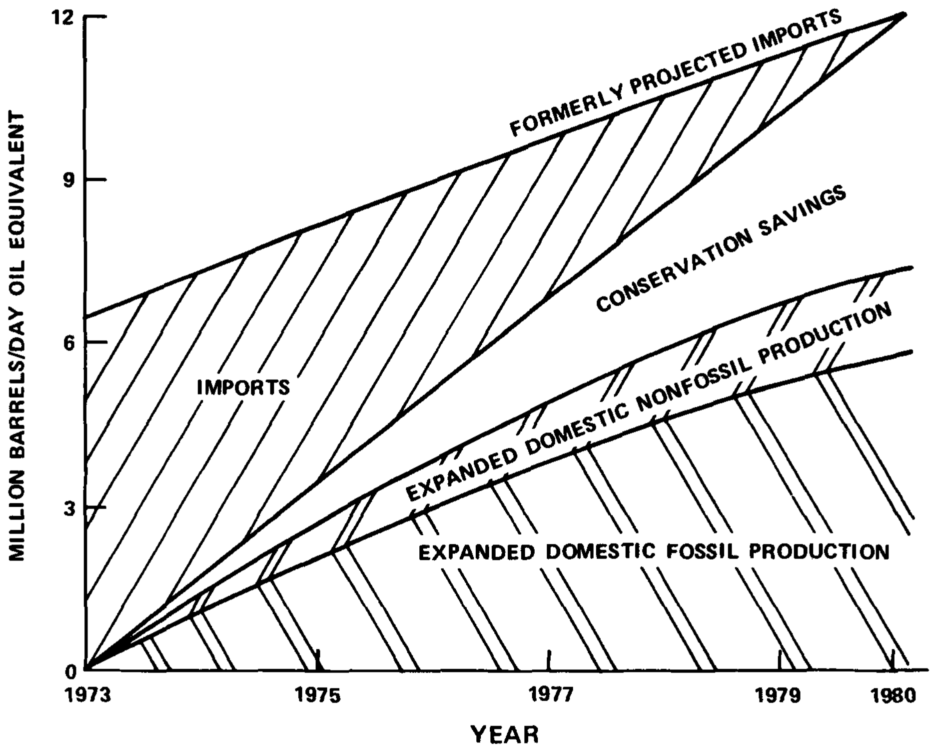
V

Figure 3-7
ENERGY FUTURE WITHOUT SELF-SUFFICIENCY



SOURCE: "UNDERSTANDING THE 'NATIONAL ENERGY DILEMMA'," JCAE, 1973

Figure 3-8
SELF-SUFFICIENCY BY 1980 THROUGH
CONSERVATION AND EXPANDED PRODUCTION



IMPORT REPLACEMENT (Million Barrels/Day Oil Equivalent)	YEAR 1973	1980
Formerly Projected Imports	6.5	12.0
Conservation Savings*		4.7
Expanded Domestic Nonfossil Production		1.5
Expanded Domestic Fossil Production		5.8

*Includes both conservation techniques and energy real price increases.

4

Tasks Required to Regain and Maintain Energy Self-Sufficiency

The President has determined that the Nation should regain energy self-sufficiency by 1980. The Nation's longer term energy goal is to maintain that self-sufficiency at minimal dollar, environmental, and social costs.

Urgent research and development and supporting policy emphasis must be placed immediately and simultaneously on five major tasks to realize these goals. These five tasks are:

- Conserve energy and energy resources.
- Increase domestic production of oil and gas.
- Substitute coal for oil and gas on a massive scale.
- Validate the nuclear option.
- Exploit renewable energy sources to the maximum extent feasible.

The major features of these tasks are set out below.

TASK 1. CONSERVE ENERGY AND ENERGY RESOURCES

Every effort short of administrative controls, if possible, must be made to reduce energy consumption and to increase the technical efficiency of the energy system. There is an overriding need for knowledge about the effects of potential policy options and of price rises on energy consumption and for an extensive data base and a usable model of the energy system. Global policy analyses of the interactions among the components of the energy system are urgently needed to identify potential conservation opportunities and the measures required to exploit them. Information from such efforts can serve to guide immediate choices among policy options. For example, such analyses would identify as candidates for energy savings those activities most destructive of the environment which are deemed least essential to society's other goals.

At the same time, urgent attention must be directed to achieving the desired end-use energy consumption with fewer energy resources. This category of goals focuses on improving the efficiency of both stationary and mobile conversion processes and of transmission, distribution, and storage systems. Large savings might come from new ways of combining existing technologies to capture what is now waste heat from certain processes to do useful work. In general, gains in efficiency may be expected to reduce undesirable environmental effects and energy costs as well as extend the useful lifetime of our domestic energy sources. The immediate gain from conservation measures will be to minimize the extra production needed from domestic resources to regain self-sufficiency.

TASK 2. INCREASE THE DOMESTIC PRODUCTION OF OIL AND GAS

The role of oil and gas is so pervasive in the Nation's energy economy that the highest priority must be given to locating and recovering more oil and gas from domestic fields and to recovering more oil from shale. Secondary and tertiary recovery methods in existing fields, improved drilling methods for offshore sites, release of gas from tight formations, and extraction of oil from shale, offer much promise for immediate and short-term payoff. Scrupulous attention to environmental risks must be ensured, but such attention cannot be allowed to interfere with production increases. Rather, work must proceed at once on methods to prevent environmental damage, e.g., oil spills and well blowouts, and to clean up after accidents that do occur. Techniques must be advanced to contain the leachings from shale residue in confined areas. In situ retorting of shale, while problematical, could have very large benefits if successful.

TASK 3. SUBSTITUTE COAL FOR OIL AND GAS ON A MASSIVE SCALE

This task can be divided into two parts. The first is to switch wherever possible to the direct use of coal where oil and gas are now used, as in boilers in industry and in central power stations. This action can be taken almost immediately. The switch would be limited primarily by the amount of coal available, the transportation capability, and the availability of equipment to modify certain plants. Coal is an enormous domestic resource, and immediate and intensive efforts must be mounted to mine more of it and burn it at acceptable emission levels. "Front-end" processes that remove excess sulfur during combustion and "back-end" processes, such as stack-gas cleanup, must receive urgent and continued attention. Special attention is needed to determine quickly the appropriate balance between the removal of micron particles and the removal of sulfur oxides. Ambient air quality standards should be considered in conjunction with extensive instrumentation and monitoring to detect adverse effects at an early stage. Processes for solvent refining of coal should be explored on a priority basis. As with shale, in situ processes, though a high-risk area, offer the prospect of very high payoff if they can be developed.

The second part of the coal-substitution task is the conversion of coal to synthetic fuels: low-BTU gas; high-BTU, or pipeline quality, gas; liquid boiler fuel; and a synthetic crude suitable as refinery stock. Some existing methods are technically feasible; however, much work is needed to achieve improved yields. This is especially true for liquid fuels, where the technologies are less advanced and the estimated product costs are relatively high. A major effort must begin now to ensure these options.

The coal effort is a good example of how short-term and mid-term programs will support each other: many of the efforts directed at improving the yield, safety, and acceptability of mining and desulfurizing coal will readily apply to the more-advanced programs.

TASK 4. VALIDATE THE NUCLEAR OPTION

A self-sufficiency based on fossil fuels can only be temporary. Though large, these resources are finite. Statements about reserves adequate to last for hundreds of years seldom speak to the feasibility, let alone the desirability, of extracting them. Their extraction and conversion create major environmental problems, and the cost of energy will continue to rise as long as major dependence is placed on them.

Moreover, oil, gas, and coal are important sources of raw materials for fertilizer and other petrochemical industries. The world's growing demands for food alone preclude continued long-term reliance on fossil fuels as the Nation's principal source of energy.

As other nations develop economically, their fuel requirements will increase rapidly, much as did those of the United States. These requirements will place growing demands on the world's supply of fossil fuels. Many argue that the Nation has a responsibility to support its high standard of living from its own resources and a responsibility to leave some of its readily available fossil resources to future generations.

Finally, concern has been expressed about the possible eventual "greenhouse" effects of increasing the atmospheric concentrations of carbon dioxide resulting from the use of fossil fuels. Future limitations on worldwide carbon dioxide emissions may be necessary. All these reasons make clear the need to move as quickly as possible to replace fossil with nonfossil fuels for energy uses.

The Nation has already begun to exploit its nonfossil energy resources. Nuclear power now generates some 5% of all electricity, and this fraction is scheduled to increase to 23% by 1980. The projected increase must be ensured and accelerated. Nonfossil sources must increase sharply their already large planned contribution to the energy supply in the next decades.

The United States has a unique opportunity to exert world leadership by advancing the development of nonfossil energy technology. As reliance on domestic fossil fuels begins to decline, the United States might export fossil fuels to other nations for a period. In the longer range future the export of nonfossil energy technology could be a major source of foreign exchange earnings and could help other nations free themselves from dependency on fossil fuels.

In the shorter term, research and development on reactor safety, waste management, fuel processing, and standardization of design is urgently needed to speed up the installation of nuclear reactors.

Accelerated research on converter and breeder reactors, to include use of the thorium cycle, offers promise of more-efficient power production and a great reduction in fuel requirements, with corresponding reductions of the problems created by mining, waste disposal, and radioactivity. Breeder reactors offer the promise of truly permanent self-sufficiency with minimal and eventually perhaps no extraction of ores. Additional effort must be directed to the elements of the nuclear fuel cycle from mining to reprocessing methods.

TASK 5. EXPLOIT RENEWABLE ENERGY SOURCES

For the long-term there is hope that environmentally clean, naturally renewed domestic sources of energy can be tapped at reasonable costs. Nuclear fusion and central-station solar power now appear to be the most promising prospects.

In the short-term and mid-term, however, much can be done and much yield can be expected from a sound program vigorously executed. For example, with available technology the economic feasibility and reliability of solar space heating and cooling should be demonstrated soon. Considerably more research and development must be done if significant amounts of the indirect sources of solar energy, such as wind currents, ocean thermal gradients, and bioconversion, are to be used. Geothermal resources are already providing significant amounts of power in certain regions. Their contribution should be increased wherever possible to reduce the need for fossil fuels.

5

The Federal Role in the National Program

The Federal Government's responsibilities in the national energy research and development program are to:

- Establish the goals of national energy policy, including those for energy research and development.
- Identify, in conjunction with private industry, the research and development needed to reach those goals.
- Ensure, through appropriate exchange of information with industry, that essential research and development is done by private sources, joint private and Government undertakings, or Government efforts.
- Accelerate technological advances throughout the energy system.
- Discharge these responsibilities in a manner consistent with the Government's nonenergy responsibilities.

Whenever national goals coincide with those of private industry, then private industry should be encouraged to attain the national goals. The free enterprise system has repeatedly demonstrated its ability to get results fast when given the proper incentives.

A competitive, free enterprise market is not well-suited to accomplish all the Nation's goals. Considerations, such as environmental concerns, basic research needs, and national security, that may not be readily integrated into the profit motive will not receive the necessary priority in the market. The Government should intervene to ensure adequate priority to considerations that are deemed necessary in the national interest, but are not funded by the private sector.

GENERAL GUIDELINES FOR FEDERAL/INDUSTRY PARTICIPATION

The major guidelines used in the development of the recommended program were to:

- Maximize industry participation, both to conserve Federal dollars and to speed the application of new processes.
- Tailor participation methods to individual industries.
- Ensure that no industry or firm realizes windfall profits at the taxpayers' expense, while preserving appropriate incentives that reward successful innovation.
- Use the best existing capabilities and expand Government facilities only when no capability exists nor can be created in the private sector.
- Press vigorously for the establishment of a single Government organization (Energy Research and Development Administration) to coordinate the national program and to plan, coordinate, and execute the predominant part of the Federal program.
- Develop Federal measures to reduce the commercial uncertainties of early application of new technologies.
- Ensure that efforts to attain energy goals do not unintentionally compromise efforts to attain other national goals (e.g., price stability, full employment, and consumer protection).
- Ensure that Federal actions taken in pursuit of other national goals also give full consideration to their impact on energy.
- Attain energy goals with minimal interference in the competitive market and in close coordination with Federal, state, and local regulatory agencies in regulated sectors.

The application of these guidelines and consultation with industry representatives show that the bulk of the private effort will be concentrated primarily on short-term objectives. Thus, the recommended Federal program does not include funds for all the short-term research and development contemplated in the national program. The best estimates possible suggest that with appropriate policies the Government might reasonably expect industry to allocate about $2.5 billion per year for direct energy-related research and development, most of it aimed at short-term payoff. The Federal program is designed to encourage private expenditures and to conduct needed short-term work over and above that expected to be funded by the private sector.

Based as it is on the profit and growth motives, the incentive for the private sector to undertake research and development expenditures diminishes as the expected time of payoff increases. Accordingly, the Federal share of the national program must be larger in meeting mid-term energy needs than in meeting short-term objectives.

Those efforts expected to yield major payoff only in the long term must depend almost entirely on Federal funding. Most of these efforts are in early stages of development and can be funded adequately without consuming a major share of the Federal budget for energy research and development.

The range of methods for Government participation extend from monitoring private actions to conducting research in Government facilities. Among the available methods are Government contracts for research and development work, cost-sharing arrangements with private concerns, use of Government facilities by private investigators, guarantees of product price, guaranteed loans, guarantees of rates of return (as in utility regulation, for example), and tariff or quota protection of the domestic market to maintain a price structure that will stimulate private activity.

One of the hardest dilemmas that will confront energy policy makers is the need on the one hand for high prices and profits to stimulate private activity and the desire on the other hand to protect consumers against undue exploitation. The objective here should be to reward to the extent possible only private activity that involves new work or increased production while avoiding windfall or "unearned" profit increases to energy-producing firms.

Another series of dilemmas will arise as measures aimed at energy goals conflict with measures aimed at other national goals. Examples will be in areas of antitrust enforcement, taxation, leasing of public lands, patent rights, and attainment of ambient air quality standards as opposed to emission standards. In these areas trade offs among the goals will be required.

Finally, a series of incentives over and above research and development expenditures will be required to move the research and development results into production quickly to regain self-sufficiency by 1980.

In some cases the Government may have to offer contingent guarantees to industry to reduce risks to a level that will ensure both direct participation in research and development and early implementation of results. In such cases (guaranteed loans, guaranteed product prices, etc.), the Government incurs a contingent obligation similar to FHA or VA mortgage guarantees. These possible obligations are not included in the Federal energy research and development budget; they are treated as possible costs of realizing the most rapid impact on energy production.

Specific measures should be tailored to fit the particular industrial conditions. The requirement for a comprehensive and consistent set of Federal policies tailored to individual industrial conditions is only one very important reason why the early creation of a Federal Energy Research and Development Administration is essential to the successful execution of the national research and development program.

RESEARCH AND DEVELOPMENT STRATEGY OPTIONS

Energy policy makers will need to make choices among a number of competing considerations. Self-sufficiency, environmental improvement, and low energy cost are the three that are central to energy issues.

Energy research and development policy makers also must decide on the relative emphasis to be given in the Federal program to these considerations. The different priorities that can be placed on each constitute the available range of research and development strategy options.

With three considerations, there are ten possible strategies: a balanced strategy that gives equal emphasis to all three, and three in which each consideration is given first priority. For example, if self-sufficiency is accorded first priority, the three strategies under that condition are: second priority to environment and third priority to low cost, or second priority to low cost and third priority to environment, or equal priority to environment and low cost.

Two major reasons dictate the selection of the self-sufficiency/environment/low-cost strategy for the Federal program. First, the three possible self-sufficiency strategies are the only ones consistent with the urgent nature of the energy problems confronting the Nation and the support of the five tasks that have to be accomplished for the Nation to regain and sustain self-sufficiency.

Second, the competitive private sector already contains within it one of the most powerful incentives ever known to reduce costs: the profit motive. There is in the private sector no corresponding motive to move toward self-sufficiency. Also, the private incentive to clean up the environment is less compelling than the profit motive. Accordingly, the Federal Government should emphasize research and development programs aimed at regaining energy self-sufficiency achieved under acceptable environmental conditions and rely on the market forces to reduce energy costs.

The implications of this recommendation must be made clear. A significant and sustained rise in the price of energy relative to other commodities can be anticipated. As the price of energy rises, there will have to be some important changes in the way energy is used. Not all of them will be welcome, but the benefits of self-sufficiency can more than offset the costs.

CRITERIA FOR FUNDING FEDERAL PROGRAMS

Federal research and development criteria for assessing priorities among competing research and development programs and proposals include: the current state of scientific knowledge; the probability of future technological success; capital, resource, labor and environmental limitations on production feasibility and cost; and geographical, political, and other constraints on the application of new technologies. When allocating money, each program must be assessed for its probability of success, the investment of research and development funds required, the timing and extent of potential payoff, and noneconomic aspects.

The following questions should be considered when allocating funds for research and development projects:

- What will the project cost in each year to completion?
- What is the probability that the project will be successfully completed and when?

- If the project is successful, how long will it take to implement the new technology?
- What is the expected amount and timing of the gain from the scheduled implementation?
- What are the projected amounts and timing of the costs of realizing that gain?
- What is the "rate of return on investment" expected from each project (the present value of expected costs subtracted from the present value of expected benefits and the result divided by the present value of projected costs)?

Projects should be ranked in order of the size of the answer to the last question, then funded in sequence down that list to the limit of the money available for energy research and development if there are no overriding noneconomic considerations. If such considerations do exist, they and their implications for the program should be stated explicitly.

Precise and accurate estimates of the quantities involved are not required to get useful guidance from this approach. While absolute levels of the quantities involved are impossible to specify with precision because of future uncertainities, the direction and extent of **differences** in the magnitude among the various projects are much easier to estimate. More can be said about how projects might differ in the future than can be said about the absolute values of the crucial parameters. One way to do this is to set out the sequence of events that has to transpire for each project to be economically viable, then evaluate those sequences which are more likely and those which are less likely, and determine whether the differences are large or small. These kinds of estimates are sufficient to provide useful funding priority guidance.

A number of specific criteria can be identified, and estimates of "high," "medium," and "low" assigned to each program area. With these, semi-quantitative indicators (not measures) can be generated. These indicators can help specify the relative priorities among programs. Indicators so derived should not be used as inflexible decision rules. Rather, they can serve as useful inputs to informed judgments about the relative amounts of money that ought to go to the various programs.

A high indicator value does not necessarily mean a large number of dollars should go to that program; it means that the program should receive all the reseach and development dollars that can be spent prudently in the area. How many dollars can be spent prudently is a determination that must come from an informed judgment of the program's history, its present position, and the prospects for its future development.

Because of the claims of higher priority programs, a low-value program may have to be held to a funding level well below that which could be spent prudently. The absolute number of dollars going into a low priority program may still exceed that going into a high priority program because of differences in the scope of the programs concerned. For example, conservation studies may be the highest priority program, but may be able to absorb prudently only a few tens of millions of dollars, while the nuclear fusion effort, having lower priority, calls for more money, yet still less than it could absorb prudently.

To be successful in augmenting energy supplies or reducing demand, a research and development proposal must show promise of success in three successive stages and must not be inconsistent with overriding noneconomic considerations. The four areas of inquiry and the major considerations in each are:

Research and Development Stage

- Adequacy of scientific base
- Probability of future technological success

Implementation and Production Stage

- Production capability
- Availability of ancillary resources
- Environmental cost consequences

Payoff Stage

- Timing of payoff
- Economics of payoff

Noneconomic Considerations

- Environmental effects not considered in costs
- National security
- Political
- Regional

A detailed explanation of the application of these criteria is contained in Appendix B. The results can provide useful guidance in the assignment of relative priorities for funding. Program rankings derived from the analysis are listed in Table 5-1 for the major elements of the recommended program.

The program rankings are not, **and are not intended to be,** definitive; they are **indicative** of the appropriate relative funding priorities derived from the recommended energy research and development strategy. They are a means by which program priorities may be estimated in the presence of large uncertainties about specific future results.

Concern is often expressed as to the availability of ancillary resources (water, transportation, land areas, manpower, capital) to support the application of a prospective new technology. While these deserve some consideration, they should not exert a major influence on **research and development** funding for two reasons.

Table 5-1

ILLUSTRATIVE PROGRAM PRIORITIES BASED ON CRITERIA

Weighted Criteria	Total Rank	Unweighted Criteria	Total Rank
Conservation	(70)	Conservation	(43)
Resource Assessment	(68)	Coal and Shale Processing	(42)
Oil and Gas	(67)	Resource Assessment	(41)
Coal and Shale Processing	(67)	Oil and Gas	(40)
Mining Coal and Shale	(64)	Fission	(39)
Fission	(63)	Mining Coal and Shale	(38)
Conversion Techniques	(57)	Conversion Techniques	(36)
Advanced Transportation Systems	(54)	Advanced Transportation Systems	(35)
Energy and Fuel Transportation Distribution and Storage	(54)	Energy and Fuel Transportation Distribution and Storage	(33)
Geothermal	(45)	Fusion	(29)
Fusion	(43)	Geothermal	(28)
Solar	(40)	Solar	(27)

First, one of the aims of the research and development itself is to reduce the major technical obstacles to implementation. Thus, a presently perceived obstacle that can be reduced is a call for more research and development, not less.

More importantly, only as application begins can realistic evaluations of these supporting resource requirements be made and the amount of the limited resources that will go to a particular energy technology be determined. All the resources needed to implement all the technologies in the research and development program exceed the available supply, but this does not mean that any research and development work should be curtailed. It means only that not all technologies are going to be implemented at their maximum possible rate. Those which are implemented, and the speed with which this is accomplished, will be decided largely by the success of the research and development program and by the market, where the users of each process must bid away from other users enough resources to support its application. The results will be reflected in the energy price from that technology, as well as in the prices of other commodities that use the same resources.

Management of the Federal Program

Two key elements are urgently required in the management of Federal energy research and development if it is to be successful: unity of effort and and flexibility.

Unity of Effort. The preceding section described one method for considering all the Nation's energy research and development needs in a common framework. The importance of such unified consideration in planning the program is self-evident. The necessity for unified direction and coordination of the program's execution is equally if not more urgent.

A first requirement for making the most rapid possible progress toward self-sufficiency is a comprehensive and detailed inventory of the opportunities for increasing production from each of the energy sources, increasing the efficiency of energy transformation and distribution, and decreasing energy and energy resource consumption. These must be defined according to common standards and evaluated by the same criteria used to determine the potential impact on the self-sufficiency goal. Centralized direction of this effort will be essential to charting the alternate paths to self-sufficiency, selecting the most sensible path for major emphasis, and providing backup options in case of delays. A single Government agency will be required to accomplish these tasks effectively.

For example, some of the early questions that will have to be resolved in the program's execution can only be answered sensibly by a single group with overall responsibility for the program. The balance between total systems approaches and the role of major systems components is one such question. Work must begin at once on all the component areas by making the best estimates possible of values for the parameters of major components (e.g., how much will oil and gas production increase; how much must coal production increase; how much coal will go to each use?). At the same time, the total system must continue to be better defined so these parameters can be adjusted as work proceeds and initial results are obtained.

Other crucial questions will relate to what kind of work and how much of it is performed in Government laboratories and in industrial facilities; technical vs. institutional or policy measures to increase production; speed of application vs. environmental constraints; speed of research work vs. cost of the final process; when to freeze a design and go for application rather than seek continued improvements; how much effort to divert to immediate concerns vs. the effort going to more distant concerns; and a host of others. The way these issues are resolved at the outset of the effort will have a major impact on the shape of the entire effort. Failure to provide unified, coordinated guidance and direction in their resolution will invite if not guarantee the program's failure. A plan for a national research and development program and the money to carry it out are only two of the four essentials of success. The other two are an effective management structure and vigorous execution responsible to changing conditions.

Flexibility. The remaining essential requirement for conducting an effective program of the dimensions recommended with the urgency demanded by our energy situation is the ability to adjust to changes as they occur. By its nature research and development is an expedition into the unknown. New knowledge, new discoveries of resources with existing techniques, and a host of other facts will generate rapid shifts in the needs of individual programs.

The specific five-year program recommended herein appears **now** to be that best suited to the Nation's needs, but it will have to be modified in light of new circumstances as it is executed. The fiscal year 1975 budget recommendations are firm; they are the way to **start** the program. But estimates for future years and even program totals should be subject to continuing review and evaluation in light of changes in the Nation's energy situation.

Flexibility in the application of funds and their transfer among programs will be essential to the capability to exploit success. Changes in priorities and reallocation of effort among programs and between the Federal and private sectors will be required. Again, only a single agency with the authority to make such shifts can capitalize on opportunities as they are discovered and shut off failures as they are identified.

Finally, flexibility in the approaches to dealing with industry will be required. The coal mining industry, the coal using industries, the oil and gas industries, the transportation industries, and others all differ in fundamental respects. What works best in one industry may be totally wrong in another where conditions differ. Accordingly, the ability to set specific goals and constraints and to select, from among the possible Federal measurements, that combination best suited for each sector will be crucial to the most effective Government/industry cooperation.

Because the majority of the energy production system is privately owned, effective Government/industry cooperation will be essential in translating the program results into increased supplies. Wherever possible, some form of cost-sharing and participatory decision making should be used.

When only Government management and funds are involved, there may be a tendency to extend a project beyond the reasonable point of cutoff, even when it is apparent to the potential industrial users that the undertaking no longer holds reasonable promise for producing useful results. Industrial management and partial industrial funding provide a method for subjecting programs to the discipline of the market place and redirecting resources in a timely manner.

International Cooperation

A final need for a centralized management capability derives from opportunities for cooperative international efforts in energy research and development. A recent interagency task force has identified the criteria that should apply in such efforts and the most promising prospects for international cooperation. The task force considered international research and development against a backdrop of four basic issues:

- Which technologies offer promise for cooperative research and development, and which countries are doing significant work worthy of cooperation?
- Should the programs be bilateral or multilateral?

- What role should U.S. industry play, and can and should the Government stimulate industrial participation?
- What will be the technology transfer and balance of trade implications of increased cooperation?

The following criteria were used to establish priorities for cooperative research:

- Useful foreign technology.
- Impact on U.S. energy deficit.
- Time to commercial utility.
- Lack of barriers to information exchange.
- Opportunities to expand cooperation.

The five criteria refer to the potential benefit to be derived from cooperative research and development, and not whether the technology in question is necessarily high on the list of current U.S. domestic priorities. The task force reached the following judgement:

- High overall priority: coal technology, geothermal, energy conservation, environmental studies, resource assessment, and transportation systems.
- Medium overall priority: conversion technology, fuel transport, fusion, hydrogen economy, reactor safety, and solar.
- Low priority: electrical transmission, energy storage, hydro, miscellaneous sources such as wind and tidal power, all other nuclear, and oil and gas technology.

Clearly a single Government agency working in conjunction with the Department of State could better realize the potential benefits from such a program and integrate them into the planning and execution of the national and Federal programs than can the existing organization, or lack thereof, for Federal energy research and development.

6

Obstacles to Realizing National Energy Goals

This chapter describes basic technological obstacles that stand in the way of decreasing energy demand and increasing energy supply and institutional factors that may act as further constraints on the choice of programs to overcome energy shortages.

TECHNOLOGICAL OBSTACLES

Task 1. Conserve Energy and Energy Resources

Reduce End-Use Consumption. Significant results in energy conservation in the absence of administrative controls cannot be attained until research has been conducted to overcome:

- Insufficient knowledge of the effects of alternative policy options.
- Inadequate data for predicting the extent to which energy consumption is responsive to increases in the relative cost of energy.
- Inadequate identification of opportunities for substituting energy-conserving practices and processes for energy-intensive ones throughout the economy.
- Lack of an adequate data base and of models for systematic analyses of the energy system and the interactions of its major components.

Improve Efficiency of Energy Use. Ways must rapidly be found to meet a given end-use energy demand with fewer energy resources.

Industrial processes use approximately 40% of all energy consumed in the United States today. Industrial processes, equipment, and methods, whether dependent on heat or on electric power are inefficient. Major increases in efficiency are possible, as demonstrated by a few pioneering industry studies. A chloride electrochemical reduction process for aluminum production is substantially more efficient than the next best alternative and also cleaner. The payoff of increased efficiency in all types of energy uses will be prompt and continuing, reducing resource use and the environmental impact of energy production and use. Major gaps in current technology are:

- Insufficient development of catalysts to substitute for heat or electric energy.
- Inadequate methods for using the waste heat of power plants and industrial processes for process heat and for space heating.
- Inadequate methods for using waste process heat to generate electricity.

Space heating and air conditioning account for almost 25% of all energy consumed in the United States today. Heating and cooling efficiency is largely dependent on building design and on the design of the conditioning unit and its control mechanisms. Future construction and modifications of present buildings should incorporate concepts leading to greater energy efficiencies. The building industry is so fragmented, however, that there is no prospect of significant impact without Government incentives, and the diverse building codes enacted by the multiplicity of independent jurisdictions complicate the problem of adopting standard designs. Principal limitations to greater efficiency are:

- Lack of a total-systems approach to the energy needs of individual buildings and clusters of adjacent buildings.
- Lack of coordination of the solar heating and cooling approach with building design.

The transportation sector accounts directly for about 25% of total fuel use and more than 50% of oil consumption. Shifts of travel practices from truck and auto to more-energy-efficient modes could reduce significantly the total energy demand and local pollution levels. Major obstacles to the shift are:

- The lack of general public acceptance of mass-transportation vehicles and systems in their current form.
- Inadequate data about the response of citizens to incentives to make more efficient use of cars.

Conversion Techniques. The conversion of fossil fuels and nuclear fuel to electricity is a relatively inefficient process. The newest central-station power plants typically have efficiencies of about 38 to 40%; the overall industry average is nearer 30%. The remainder is lost in the form of waste heat, which contributes to pollution. Demand for electricity has grown more rapidly than that for other forms of energy; its doubling rate is now 10 years.

To supplement the regular steam cycle, generating plants could, with so-called "topping cycles," use the high-temperature spectrum of the combustion gases. These include magnetohydrodynamic (MHD) cycles, liquid-metal cycles, or direct turbine drive by the hot gases before they are used to form steam. An increase in overall system efficiency of 15% is theoretically possible; the savings in fuel would be enormous (in the range of 25% or more), and waste-heat rejection would be reduced by as much as 40 to 45%, which would decrease environmental problems as well. The need is urgent for work on:

- High-temperature gas turbine, potassium topping cycle, and magnetohydrodynamics.
- Materials for use with high-temperature working fluids.
- Cost and life of fuel cells.
- Scale factors for commercial-sized equipment.
- Heat rejection and utilization technology for base-load plants.
- Methods for combining different technologies and processes to achieve greater efficiencies and reduce total heat rejection.

Energy Transmission, Distribution, and Storage. Once electric energy is generated at a power plant, it may travel many miles to the consumer. In the process, voltages are stepped up and down. In general, the higher the voltage, the smaller the losses in transmission, but the higher the capital requirement for the line. Transmission lines are designed to optimize the trade offs between these economic factors. The ever-increasing demand for electric energy will require more power lines in the future and power lines of increased capacity. Major difficulties are:

- Resolution of land-use and visual-impact problems to permit use of more efficient, higher capacity overhead transmission systems.
- Costly, inefficient underground cables with inadequate capacity.
- Instantaneous matching of generation to load within and between electric power systems.
- Lack of adequate, efficient energy storage systems.

Advanced Transportation Systems. Transportation uses 25% of all energy consumed in the United States at an efficiency that rarely exceeds 20%. Furthermore, automotive and aircraft engines today are designed to run only on refinery products of crude oil, a pattern that cannot be changed significantly in the near future. Because of their intolerance for fuel substitutes, automotive and aircraft engines may set the lower limit on needs for liquid petroleum products. The supply of natural gas, which is a suitable alternate fuel, is even more constrained than that of liquid petroleum. When an automotive engine converts fuel to mechanical energy, there are other losses in the automotive power train that further reduce system efficiency. Moreover, vehicles are designed to optimize features other than fuel economy. Primary technological blockages to change are:

- Lack of vehicles designed to provide efficient transportation service with minimum fuel consumption.
- Lack of automotive engines that are both highly efficient and environmentally acceptable.
- Inability to use substitute fuels and fuel supplements (e.g., methanol) on a large scale.
- Inefficient automotive power trains.

Task 2. Increase Production of Oil and Gas.

Oil and Gas. The ratio of proven domestic reserves to production for both oil and gas continues to fall. The recovery of oil from operating fields averages only some 30% of the oil in place and is only some 40% in the newest fields. Every 1% increase in recovery rates presents an addition of 4 billion barrels to U.S. proven reserves, an amount equal to about two-thirds of present annual consumption.

Much gas exists in impermeable rock formations and cannot presently be recovered economically. Moreover, theories that explain the formation of hydrocarbon resources predict the existence of large undiscovered reserves. Large areas contiguous to the continental United States may contain undiscovered reserves, although some of them may exist at depths that cannot be explored and tapped economically with today's exploration and drilling techniques. Major technical obstacles to a rapid increase in domestic production of oil and gas are:

- Lack of economical recovery methods for oil and gas remaining in producing fields.
- Lack of recovery methods for gas trapped in impermeable formations.
- Lack of economic discovery and recovery methods for oil and gas at great depths.
- Inadequate methods for preventing large oil spills and for containing and cleaning up spills with minimum damage.

Shale Deposits. Oil can be produced by retorting shale to generate a crude-oil product from the hydrocarbon-rich kerogens of the shale deposits. Both nonnuclear and nuclear methods of fracturing rock offer promise of releasing the shale in forms suitable for in situ retorting. Shale as a source of oil has the advantage that its BTU content per barrel of produced oil is slightly higher than that of the natural petroleum product. In addition, shale has a higher hydrogen content than does coal; so less hydrogen is needed to produce the liquid fuel. Some 75% of the richer shale deposits are located on federally owned property. Major recovery problems are:

- Lack of economically viable and technically reliable methods for retorting shale deposits, especially in situ.
- Lack of adequate technology for fracturing shale deposits in situ.
- Lack of environmentally acceptable methods of handling the shale debris generated by above ground retorting.

Task 3. Substitute Coal for Oil and Gas

Mining and Direct Use of Coal. The energy content of known domestic coal reserves is significantly larger than that of any other energy resource available with today's technology. However, the use of coal has dropped sharply in the past two decades (Chapter 3). Approximately 60% of coal reserves have a sulfur content that is so high that combustion emissions will not meet air quality standards without the use of new emission-control techniques. The decline in the use of coal has resulted in a contraction of the industrial base. Major obstacles to the use of coal are:

- Lack of proven techniques for reclaiming surface-mined areas, especially in semiarid and arid regions.
- Low productivity of underground mining methods.
- Limited ability to burn high-sulfur coal in ways that meet established pollutant (sulfur oxides) emission standards.
- Production of undesirable waste products by current stack-gas scrubbing methods.
- Lack of effective methods for removing micron particulates from stack gases.

Production of Gas and Oil from Coal. *Low-BTU Gas from Coal.* Oil and gas have been produced from coal for many years. The technology was used in Germany during World War II, but it has not been economically competitive with other sources of oil and gas. Before natural gas was widely used as an energy source, synthetic gas was manufactured from coal. It is acceptable by modern standards. A gasifier using air should be able to produce a clean low-BTU fuel that could be burned in most fossil-fired electric utility boilers as well as in smaller industrial boilers. Only 35 to 40% of the original heat content of the coal would be lost in the conversion process. Rapid installation of improved gasifiers could be expected in the utility industry. The principal impediments are:

- Inadequate development of gasifiers for low-BTU product.
- Lack of a high-temperature desulfurization process to clean up the gas.
- Lack of advanced techniques to salvage the excess heat loss.
- High cost of transporting low-BTU gas.

High-BTU Gas and Liquids from Coal. Processes for producing high-BTU gas and liquids from coal rely on increasing the ratio of hydrogen to carbon over that found in coal. Given sufficient price incentives, industry should be able to produce high-BTU gas from coal at costs competitive with naphtha conversion, imported liquified natural gas, or natural gas transported from Alaska. The product from liquefaction processes contains less than half the hydrogen necessary to make pipeline-quality gas from coal but less of the original heat value is lost in the process. The liquid product is also easier to transport and store. Principal obstacles to production are:

- Need for a breakthrough in production of hydrogen by catalysis or other methods.
- High cost of producing methanol from coal.
- Lack of methods to remove organically bound sulfur in coal.
- Insufficient knowledge about engineering needs to accommodate various grades and types of coal.
- Environmental constraints, particularly the availability of water supplies.

Task 4. Validate the Nuclear Option

Current Nuclear Reactors. The present generation of converter nuclear reactors is being installed at a rate well below original expectations. In addition to construction delays, licensing delays, and environmental and safety concerns, the evolutionary nature of the industry has resulted in continual design changes in successive reactors. Each new design modification has required a full-scale review for licensing by the Atomic Energy Commission. The current plans for high-level waste disposal call for storage of fission-product waste above ground for up to 100 years while a permanent disposal method can be developed. There is an urgent need to improve the following conditions:

- Inefficient fuel utilization of present light-water reactor designs.
- Shortage of experimentally confirmed test data on environmental and safety problems associated with converter reactors.
- Plutonium and fission-product waste handling and disposal problems.
- Lack of standardization in reactor design and site selection procedures.

Fuels. The current family of nuclear converter reactors uses a relatively inexpensive fuel derived from high-grade uranium and thorium ores. Known reserves of these high-grade ores are limited, and medium-grade ores have not been well explored. To support the expected growth in nuclear power plant capacity, the uranium mining industry must expand its output fivefold in the next 12 years. Obstacles to expanded use are:

- Lack of techniques for mining rich uranium ores without making lower grades of ore less accessible for future mining.
- Need for more-efficient enrichment techniques.
- Need for more-efficient fabrication and reprocessing techniques.

Breeder Reactors. Breeder reactors (liquid metal fast breeder, gas cooled fast breeder, molten salt breeder, etc.) are necessary to provide longer term sources of energy from nuclear fission because supplies of low-cost fissionable material are limited. The development of fuels and materials in turn will dictate reactor-design concepts. Work must be done on:

- Technical fuel and materials problems associated with breeder reactors.
- Excessive doubling time and specific fuel inventory of current designs.

Task 5. Exploit Renewable Energy Sources

Geothermal. At several locations geothermal energy has already been harnessed in the form of dry steam (Geysers, California) or hot water (Wairaiki, New Zealand), but such locations are rare and do not contribute significantly to the energy supply. Larger reservoirs of geothermal energy exist in the form of hot rock, hot brine, geopressured zones, and magma.

Many such sources contain heat energy at temperatures that are too low for use in conventional power-generation systems. Other sources contain contaminating salts or other minerals. Technical impediments to early increased use are:

- Lack of economical ways to find and assess geothermal reservoirs and determine their nature.
- Absence of recovery and use techniques for low-temperature or contaminated geothermal resources.
- Minimal understanding or control of potential environmental insults (earthquakes, tremors, and disposal of vast amounts of noxious gases, minerals, and salts) that might result from substantial geothermal exploitation.

Solar. For many years solar energy has been used directly on a small scale to heat water for homes or provide heat to grow plants. Unless solar energy is concentrated, however, the temperature rise associated with solar heating is too low to produce power with conventional generating techniques. Weather and day-night variations make the supply of solar energy intermittent and require that storage systems be provided for times when sunlight is inadequate.

Decentralized solar systems for space heating, water heating, and air conditioning in buildings are technically feasible today. Operating costs are appealing, but initial capital costs are high. Thus, there is no significant market force to create the necessary industry. Demonstrations with Government buildings might help stimulate a significant market for commercial buildings in the near future. Principal constraints are:

- Inefficient solar-energy collection technques.
- Inefficient energy storage techniques.
- High capital costs for decentralized heating and cooling systems.

Fusion. If fusion reactors become technically feasible, the world's oceans will provide an inexhaustible supply of fuel. Several approaches to the concept are being explored. Although recent successes are encouraging, demonstrating technical feasibility and completing the necessary reactor concepts will take considerable time. Principal difficulties are:

- Lack of adequate testing facilities to conduct critical scientific experiments.
- Lack of knowledge as to which, if any, of the suggested approaches will lead to success.
- Insufficient development of materials for planned reactors.

General Requirements

Environment. Energy production and use have been major contributors to detrimental changes in air, water, and land quality. Increasing per capita consumption of energy has been directly related to increasing insult to the environment. The relationship must be altered if desired environmental standards are to be attained.

It has only recently been realized that efforts to increase the standard of living through increased energy use may have undesirable environmental impacts. As a result, research has been initiated into the nature of these impacts, which arise from all phases of the energy cycle from fuel exploration and extraction to energy conversion and waste management. Major gaps include:

- Inadequate knowledge of the physical and chemical transport processes by which pollutants become distributed in the environment and find their way to man.
- Lack of knowledge about the health, ecological, welfare, and social impacts of various energy systems and the pollutants they generate. Such knowledge is vitally needed to set standards, to establish guidelines for the siting of energy systems, and to direct research to control and ameliorate these impacts.

Basic Research. Fundamental knowledge of the physical, biological, economic, and social laws that govern living patterns and the properties of matter has been the cornerstone of man's increasing control over the forces of nature. The energy system of the Nation is so complex that there is not a single discipline that does not play some part in its functioning. Increases in fundamental knowledge should lead to greater understanding, and such understanding should contribute to more efficient operation of the system.

Much technological development has been characterized by empirical process development. More often than not it has become difficult to move beyond certain barriers because of a lack of fundamental knowledge. In such cases, basic disciplines have been called upon to determine what relationships existed and to find approaches to overcoming the problem. With recognition of the energy shortage and with forecasts of increasing shortages for many years, maintaining the competence to react quickly to such calls for assistance is essential. Broad areas for basic research reflect:

- Insufficient knowledge of the physical and chemical nature of matter.
- Insufficient knowledge of biology and biological processes.
- Insufficient knowledge of the economic and social interactions of man.

Systems Analysis. The complexities and dynamics of the United States energy system are such that it is virtually impossible to discern even the major interactions that occur throughout the system or to predict the effects of changes to the system. Systems analysis is presently limited by:

- Lack of a valid energy model.
- Lack of a valid up-to-date data base for the model.

INSTITUTIONAL CONSTRAINTS ON TECHNOLOGICAL DEVELOPMENT

Federal and State Environmental Laws and Regulations

The National Environmental Policy Act (NEPA) of 1969 was a significant recognition by the Congress and the Administration that our national growth could no longer continue uninhibited by concern for the environment. The Act requires that an Environmental Impact Statement be published in draft form no later than 90 days before a "significant Federal action" is taken that could have an effect on the environment. A final report must be published no later than 30 days before that action. Recent court interpretations of the Act and guidelines dictate that the impact statements must be developed to support Congressional authorization and appropriation for the "activity." Thus all new or significantly altered programs will require the preparation of Environmental Impact Statements before authorization or appropriations.

Environmental standards issued by either the Federal Go\ernment or state governments should not be considered constraints to technological development. Rather, they set requirements for research and development that must be met if the technology is to be implemented within the respective jurisdictions. There is considerable concern about the validity of many such standards that have been based upon incomplete data and analysis or a complete lack of knowledge regarding the impact of certain pollutants on the environment. For instance, a major technological objective is to determine the effects of pollutants on the ecosystem and its inhabitants. That determination could establish a firmer basis for environmental standards, and the standards, in turn, would determine technological objectives for research and development efforts.

The pace of development of particular types of energy may ultimately be related to public acceptance. Delays in the environmental research program could result in significant delays in the preparation of environmental impact statements, licensing of power-generation facilities, and the implementation of various energy technologies.

Land Use and Water Mangement

The use of land for energy-related activities, such as fuel extraction, siting of fuel-conversion and power-generating facilities, transmission-line rights-of-way, and waste-management requirements, is becoming a significant factor. Regional and national management policies must be developed to accommodate competing needs for land and water for development of energy resources, wildlife conservation, recreation, irrigation and agricultural programs, and lumber and paper-pulp industries. Mining and reclamation and especially conversion processes for coal require large amounts of water, and water is not plentiful in those areas of the West where vast reserves of coal are located. An equitable distribution of land and water resources to competing claims must be devised. Such an integrated policy will be required to maintain the Nation's scenic beauty and ecological integrity as it meets its energy needs.

Federal and State Laws and Regulations Governing Health and Safety of Miners and Industrial Workers

The enactment of such laws as the Operational Safety and Health Act (OSHA) has had a widespread impact on industry, generally in terms of increased requirements for capital expenditures to provide much-needed additional safeguards for workers' health and safety and has also resulted in decreased productivity.

New technological developments should produce equipment and methods that are consistent with the laws and regulations. As such, the laws and regulations are not constraints to technological development but are an objective of such development.

Manpower Availability for Research and Development

In the late 1960s, employment opportunities for scientists and engineers declined owing largely to the termination of large programs in the aerospace industries. More recently, conditions have stabilized, and employment among scientists and engineers is high. A major increase in research and development funding could require a major increase in scientific and technical personnel.

If major increases in research and development funding are directed into new fields, the pace may be limited by the rate at which investigators can be educated, trained, or retrained to work in those areas. More importantly, most of the program categories comprising energy research and development are multidisciplinary. They rely on many of the same disciplines for both research and development. A shortage of trained manpower can create a competitive atmosphere that could result in spiraling wages and relatively inefficient use of research and development dollars. Currently the number of proposals for energy and energy-related research and development projects by firms and individuals in academic positions indicates that manpower is available for additional work.

The universities and industry have the greatest potential for producing new scientific and technical manpower. Research and development funds channeled to them would produce, in addition to increased knowledge, a large working force for future research and development. This force would comprise both undergraduate and graduate students and older workers retrained for new fields. Trained personnel can be retrained within a year or two and well-trained graduate students can be produced within two to three years.

These limitations on the growth of an available manpower pool and the hazards of attempting to radically increase funding for programs that would compete for scientific manpower dictate that extreme care be exercised in designing the energy research and development program for the next five years. If major acceleration is necessary in certain program areas, such acceleration may entail costs not only in dollars but also in the loss of capability to enhance or continue research and development in some competing programs.

Government Policies Concerning the Exchange of Information Between Large Corporations (Antitrust Laws) and Patent Rights

The public and privately owned electric utilities are regulated and have formed the Electric Power Research Institute (EPRI) to use funds charged to the rate base to conduct research and development of benefit to the entire industry.

By contrast, companies in the oil industry are specifically precluded from joining together in such a venture. As a result, each oil company must work on its own research and development goals; much duplication results. Since different oil fields have different physical characteristics, a wide variety of techniques has been developed for drilling, control, production, and stimulation of oil and gas. If each company could benefit from the experience of others, the net result should be more efficient operations and greater production. What does not exist and is precluded from existing is a central clearinghouse for research and development data and information that is in the hands of individual oil and gas companies. If solutions are developed by individual companies, proprietary rights could preclude widespread application or even application in regions where most appropriate. The oil industry is spending more than $600 million annually for research and development. With existing constraints, however, coordinated programs in the industry leading to the necessary solutions are not possible.

The oil industry has been reluctant to undertake cooperative efforts with the Government because rights to proprietary data could be compromised. Both patentable and unpatentable data are involved.

The same is true for other industries. Individual companies fear that funds invested in research and development would not be returned if the benefits are afforded to the industry as a whole.

The concept embodied in EPRI partially solves the problem by permitting the industry to share the risk as well as the benefit. When only one company or a part of the industry has an interest, however, it should be accorded some right to the advantages of research and development when it shares risk with the Government. It appears inconsistent to assume that, because taxpayers' dollars are spent to enhance the public good, an industry that risks capital along with the taxpayer should not be allowed to derive specific benefit. This area needs much consideration.

Government Policies Concerning Leasing of Federal Lands

Much of the oil, gas, oil shale, and geothermal resources and reserves in the United States are on public lands or beneath U.S. waters. The exploration and exploitation of those lands requires Government consent through leasing. Many such areas have not been opened to leasing, and vast reserves and resources have yet to be tapped. Although the outer continental shelf in the Atlantic Ocean may contain as much or more oil and associated gas than the Alaskan North Slope, there is as yet no leasing program for that area, and exploitation cannot be undertaken.

A similar situation exists for the oil-shale reserves located in the Piceance Creek Basin of western Colorado. About 75% of the rich shale deposits are located on federally owned property. Although the development of these areas is not primarily a research and development function, the lack of an adequate assessment of the potential resource base is a significant obstacle to energy policy formulation and research and development planning.

Market Uncertainties

Industry cannot predict with any degree of certainty future market conditions, e.g., the effects of the rising prices of imported oil and the regulated price of natural gas. The significance of these conditions lies in the fact that projected shortages in the supply of these commodities probably will not be overcome by private incentives as long as major market uncertainties exist.

Short-run self-sufficiency can be attained only by imposing measures that reduce the demand for energy to the maximum amounts that can be supplied from domestic resources. Other policy decisions that permit the maximum increase in domestic production will be required to realize short-term increases in the production of energy from domestic resources. Measures to increase domestic supply must continue with a view to relaxing the nonmarket measures imposed to reduce consumption. The first step in this direction is to accelerate the implementation of existing technologies for producing energy from domestic resources.

The overwhelming majority of the domestic production capability resides in the private sector. Private-sector investment decisions are made on the basis of expectations regarding future prices of energy rather than current prices. Thus, in the absence of Government policies to reduce the commercial uncertainties of increasing domestic production, there will be a substantial time lag in the implementation of existing technology until domestic producers are convinced that the high prices are going to prevail for long enough to make their investment profitable.

Moreover, other obstacles to rapid construction of additional domestic production capacity must be removed. Leasing policies that make available potential sources of domestic fuels must be devised. Guarantees of prices, guarantees of rates of return on investment, tax write-off policies, depletion allowances, and other risk-sharing measures to reduce the uncertainty of commercial ventures to acceptable levels must be considered. The dilemma confronting the Federal Government is that risk-reducing measures may diminish the incentive for private-sector research and development efforts aimed at reducing the costs of domestic production.

Capital investments for supporting functions may become limiting. For example, transportation of coal to market or to distant conversion plants will require revitalization of the rail industry or construction of special slurry pipelines.

There are two fundamental difficulties with a market approach to achieving domestic energy self-sufficiency. The effectiveness of the approach depends on the expectations of private producers about the continued high level of energy prices for substantial periods in the future. Given the potential availability of cheap foreign sources of energy materials, private producers must weigh carefully the risks of a major investment in a high-cost technology, using domestic resources. Supplies that can be cut off quickly can be turned on again as quickly. A private producer who makes a major investment in an oil-shale plant that can produce and sell oil for $5 a barrel can find himself in an untenable position if, soon after production begins, oil at $3 a barrel becomes available from foreign sources. Thus, relying primarily on market forces to generate increased domestic production implies an extended period of administrative controls to restrict consumption to available domestic supplies.

Research and development expenditures are justified for a commercial enterprise only with the expectation that they will lead to a sufficiently large increase in profits to provide an acceptable rate of return, compared to alternative uses of the limited capital available to the firm. In a situation without government-guaranteed product prices, there is no assurance that a private concern would find major research and development expenditures, with all the uncertainties involved, an attractive investment compared to additional productive capacity at guaranteed prices or rates of return.

7

Objectives of the National Energy Research and Development Program

The technical and scientific obstacles and the various political, environmental, manpower, and legal constraints to implementation of vitally needed energy technologies have been discussed in the previous chapter. The accelerated energy research and development program recommended in this report is designed to overcome these obstacles as expeditiously as possible.

It is essential in planning a balanced research and development program both to meet short-term needs and to ensure the means of meeting the needs of the decades beyond the short-term. The current scientific and technological limitations on various promising programs are reflected in the time required before commercial application of program results can be implemented. In this chapter the specific technological objectives sought for the time periods defined as short-, mid-, and long-term are summarized. This listing indicates the allocation of effort according to the different time periods within which the beginning of commercial payoff is expected.

NEAR- OR SHORT-TERM (PRESENT TO 1985)

This category includes research and development objectives that enhance the implementation of existing technologies, identify additional resources, and improve the efficiency of existing techniques, practices, and processes. Particular attention is given to removing barriers to public acceptance, satisfying existing standards, and developing an improved basis for standards in all energy production and use areas. In the list that follows, objectives with most immediate commercial payoff in energy production or conservation are marked with a •.

Task 1. Conserve Energy and Energy Resources

• Identify and quantify energy-conserving practices and processes throughout the economy.

- Develop a model of the energy system and an appropriate data base; use the model to improve the quantitative understanding of the energy system and its interactions and to assist managers to better plan and manage energy research and development.
- Increase the efficiency and capacity of electrical transmission and distribution systems, both above and below ground.
- Increase the efficiency and capacity of energy storage systems.
- Develop combined-cycle technology.
- Develop materials and technologies for high-temperature "topping cycles," including potassium topping cycles and magneto-hydrodynamics.
- Demonstrate techniques and consumer incentives that shift demand to more efficient transportation modes for people and goods for both urban and inter-city travel.
- Evaluate and demonstrate vehicle designs that optimize fuel economy and develop more efficient engines that are environmentally acceptable.

These objectives will enhance the efficiency, acceptability, or resource base of existing energy technologies. Progress in achieving these objectives will help attain the goal of energy self-sufficiency and will clarify choices among mid-term and long-term energy research and development goals as time goes on.

Task 2. Increase the Domestic Production of Oil and Gas

- Demonstrate effectiveness of new and currently available methods for secondary and tertiary recovery from existing oil and gas fields and publicize results.
- Develop methodologies to recover gas from tight formations.
- Improve methods for assessing potential oil and gas recovery from offshore sites and oil shales.

Task 3. Substitute Coal for Oil and Gas on a Massive Scale

- Improve emission-control technology for coal, especially with second-generation stack-gas cleaners.
- Mine coal with improved techniques and more effective reclamation.
- Improve gasifiers for production of low-BTU gas.
- Enhance supplies of hydrogen for coal conversion technologies.
- Develop materials for the construction and operation of coal conversion plants and develop methods for handling solids, including grinding, transporting, and separating from liquids.
- Demonstrate economic viability and reliability of the conversion of coal to gas and oil.

Task 4. Validate the Nuclear Option

- Evaluate environmental and safety problems associated with converter reactors.

- Standardize nuclear reactor site selection procedures.
- Demonstrate safe procedures for handling and storing radioactive materials, including plutonium.
- Develop long-term disposal procedures for radioactive wastes, including plutonium.
- Improve enrichment techniques for uranium.
- Improve fuel fabrication and reprocessing methods.

Task 5. Exploit Renewable Energy Sources

- Reduce capital costs for solar heating and cooling units.
- Find and assess potential reservoirs of geothermal energy.
- Develop improved methods for extraction of heat from geothermal sources.
- Assess potential dangers of disturbing geological formations by extracting geothermal resources.

MID-TERM PERIOD (1986-2000)

Mid-term energy research and development program goals aim at providing alternative energy sources and increased ability to substitute more plentiful fuels for scarcer ones. Conservation and efficiency measures, conversion of coal to gas and oil, breeder reactors, and certain solar and geothermal sources are prime elements of the mid-term program. The long lead time for development and implementation of these promising technologies makes it urgent to accelerate funding now to meet expected energy demands more than a decade from now.

Task 1. Conserve Energy and Energy Resources

- Demonstrate gains in efficiency from combined-cycle technologies.
- Develop engines capable of using a greater variety of fuels.

Task 2. Increase the Domestic Production of Oil and Gas

- Demonstrate the economic viability of oil recovery from oil shale.

Task 3. Substitute Coal for Oil and Gas on a Massive Scale

- Improve the economic viability and reliability of conversion of coal to oil and gas.
- Develop improved catalysts for fuel conversion processes.
- Maintain efforts to assess and minimize environmental impacts of energy production.

Task 4. Validate the Nuclear Option

- Demonstrate economic viability and reliability of various breeder reactors.

- Evaluate environmental and safety aspects of breeder reactors.
- Develop fuels and materials for advanced reactors.

Task 5. Exploit Renewable Energy Sources

- Demonstrate methods to produce significant amounts of electricity from direct solar incidence, from ocean thermal gradients, from wind, etc.
- Develop photovoltaic, thermoelectric, and bioconversion techniques to a significant level of productivity.
- Demonstrate economic viability of advanced geothermal methodologies.
- Demonstrate technical viability of thermonuclear fusion technologies.

LONG-TERM PERIOD (BEYOND YEAR 2000)

Many presently unanticipated variables, of course, will become important in the long-term period. Changes in the organization of society, in the patterns of transportation and other energy uses, in the needs of industry, and in overall economic growth patterns may occur. The long-term goal of the energy research and development program for self-sufficiency is the production of adequate amounts of environmentally clean, low-cost fuels from relatively inexhaustible domestic sources. Energy should be available in forms best suited to the energy needs of the various sectors of the economy. Specific objectives include:

Task 1. Conserve Energy and Energy Resources

- Improve technologies for conversion of fuels to electricity.
- Improve methods for transmission, distribution, and storage of energy.

Task 5. Exploit Renewable Energy Sources

- Develop large-scale direct and indirect solar-energy conversion programs.
- Develop methods for producing hydrogen in large quantities at low cost.
- Develop fusion technologies to economically viable status.
- Provide advanced materials for fusion reactors.

Supporting Programs

Certain supporting objectives in closely allied areas must be pursued as complements to the specific energy objectives set out above. The most important of these are:

- Enhance basic research into energy systems and fuel sources.

- Continue basic research into chemistry, physics, geology, and biology to identify new potentials and provide the basis of knowledge for solution of problems that experience shows will arise.
- Establish the nature, emission patterns, distribution in the environment, and ecological and medical effects of pollutants.
- Provide improved bases of knowledge for setting environmental standards and minimizing environmental impacts from energy technologies.
- Develop detailed methods to enhance environmental and ecological integrity and overcome any necessary but undesirable impacts that have accumulated.
- Create and sustain an adequate supply of scientifically and technically competent manpower to support the operation of the energy system and the research and development program.

Analysis of these objectives and the time period when they are currently expected to be achieved is a useful input to the process of designing a balanced national energy research and development program.

Appendix A

FY 1975-1979 ENERGY R&D PROGRAMS AND SUPPORTING PROGRAMS

This appendix outlines the recommended national energy research and development program and supporting program. The appendix includes discussions of:

- Program Goals
- FY 1975-1979 Program Objectives
- Contributions to the Energy System If Success Is Achieved
- Program Plan
- Supporting Evidence
- Budget

TASK 1—CONSERVE ENERGY AND ENERGY RESOURCES

A. REDUCED CONSUMPTION $210M

Program Goals:

1. **End-Use Conservation** $150M

To conserve energy and energy fuels by reducing the rate of growth in consumption and to achieve this reduction while maintaining an acceptable standard of living and environment, under conditions of minimal social and economic dislocation.

2. **Improved Management** .... $ 60M

To conserve energy, energy sources, and energy research and development resources by providing analytic tools for comparative analyses of alternative energy strategies that will assist energy policy and energy research and development policy decision makers in establishing policies.

FY 75-79 Program Objectives:

1. **End-Use Conservation**

   a. To maximize specific energy efficiency in buildings by developing and demonstrating improved design, construction techniques and practices, operational methods and maintenance practices, and use of materials that require less energy for production.
   b. To reduce energy consumption in industrial processes by developing and demonstrating improved design, construction techniques and practices, operational methods, and maintenance practices and the use of materials that require less energy for production.
   c. To increase the energy efficiency of transportation systems by developing and demonstrating more efficient utilization of alternate modes, patterns of traffic flow, coordination of systems to urban growth patterns, and use of local regulations.
   d. To demonstrate the energy efficiencies to be derived from integrated utility systems that would provide a community with all utility services from a single plant.
   e. To develop appropriate information and data, with cross-energy-sector applications, for analysis of the implications of demographic trends, land use alternatives, and new technologies in terms of their impact on energy demands.

2. **Improved Management**

   a. Develop and maintain an adequate base of information and data on and improve existing and develop new quantitative models of the U.S. energy system in order to provide the analytical tools required for analyses of alternative energy policies or management concepts.

b. Conduct assessments, including evaluation of environmental, economic, and social factors, of emerging energy technologies and integrate the results of those assessments into evolving national energy policies and strategies.
c. Develop evaluation criteria for the selection of energy research and development strategy alternatives and identify the trade offs implicit to these alternatives.
d. Develop recommendations for systematic management of energy research and development including identification of total resource needs and the allocation of those resources among competing programs, taking into consideration the appropriate roles for Federal and private funding.

Contributions to the Energy System If Success Is Achieved:

1. End-Use Conservation

The potential savings available through the application of conservation measures are obviously very large and difficult to predict. A 20% savings by 2000 is a conservative estimate. If 30% of the existing buildings in the U.S. are modified so that their heating and cooling loads are reduced 40% and 30%, respectively, a savings of 3% of the present total annual energy used in the U.S. will be realized.

If 50% of the new buildings built each year incorporate energy conservation design features that result in a 40% savings in consumption, a total savings of 15% of the present U.S. consumption would be realized at the end of 10 years.

Ultimately a 30% reduction in primary fuel requirements for industrial thermal processes is a realistic goal, through improved thermal processes and waste energy utilization.

Improved transportation efficiency, especially improved auto occupancy and improved management of freight, could reduce projected transportation demand by about 5% by 1978 and 10% by the year 2000.

Market analysis shows that Modular Integrated Utility Systems (combinations of various utility services in a single facility) can be utilized to service 16% of all new construction. Based on this estimate, energy requirements for space heating, hot water, air conditioning, and electricity in new construction can be reduced 35% by 1986—a reduction of 8.5% of total energy requirements for residential utilities.

2. Improved Management

Improved management planning using modern analytic techniques and a current data base can provide a means for rapid objective assessment of energy system requirements, trends, capabilities, and limitations. The decision maker would have at his disposal a more rational basis for assessing trade-off options and the allocation of resources to meet either energy needs or research and development requirements. Viable options for program planning can be analyzed to optimize payoff with minimum expenditures of resources.

Program Plan:

1. End-Use Conservation

Since too little is known about the specific opportunities for research and development leading to more efficient equipment, building, and process design, early program emphasis must be on problem definition and program design and formulation. The FY 1975 objectives and expenditures must, if necessary, be applied to "software"—or studies leading to program formulation. That activity will be supplemented by an acceleration of those programs already underway where specific objectives are clear (e.g., Modular Integrated Utility Systems—MIUS).

The software results are expected to include numerous proposals for "hard" research and development activities that can be begun immediately, and a rapid rise in program funding levels is anticipated. Concepts for energy conservation abound, but their implicit effects are essentially unknown. Once those effects are better defined, it should be possible to move directly to demonstration projects in many fields. Other "software" results are expected to specify the need for more research and development on component or material design that would result in a rapid rise in laboratory experimentation.

2. Improved Management

Improved management must begin with the development of an open-ended data base and models that will provide for forecasting of impacts and estimated results of various research and development efforts. A second level of effort will be directed toward analyzing those alternative models on a quantitative basis and translating the results into management tools for evaluation of research to be undertaken and research and development underway.

Supporting Evidence:

1. End-Use Conservation

The general subject area of process and utilizing-device efficiency is so broad that a primary necessity exists to define those topics of highest potential "payoff" before detailed technical investigation is begun in earnest. The range of disparity between theoretical requirements for energy and actual use patterns shows that there is a wide range of opportunities for increasing efficiency. Land, building, and equipment designers and contractors, industrial users of energy, and the individual consumers comprise a widely disparate field of potential research and development partners. Clearly, only the Federal Government can lead in such a fragmented area of investigation, development, and demonstration. It should be noted that many governmental pricing research and development regulatory policies have been based on an effort to promote cheaper or more abundant energy. Effort will be needed to smooth a transition from some of these policies.

Research and development conducted under the aegis of the Government can produce new standards for performance and design that would support policy incentives by the Executive and the Congress, and demonstration of more efficient designs can lead to the adoption of new equipment, methods, and construction that will produce savings for the user as well as the Nation.

2. Improved Management

Systems and planning analysis functions exist in all Government agencies that are currently active in energy or energy-related research and development. Such functions are necessary for program management and analysis. However, there does not exist the technological base for management and analysis of energy policy and research and development. Decision makers are forced to rely on multiple data bases and systems for analysis purposes. Both central policy coordinators and individual program directors can benefit from centralized planning and analysis models in addition to the requisite agency support offices.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
End Use Conservation						
Buildings	6.2	10.0	11.0	11.6	11.2	50.0
Industry	5.4	9.0	14.0	12.8	13.8	55.0
Transportation	1.8	4.2	4.5	3.0	1.5	15.0
Integrated Utility Systems	4.5	5.0	4.0	1.0	0.5	15.0
Cross Energy Sector Studies	2.0	3.5	4.0	3.0	2.5	15.0
TOTAL	19.9	31.7	37.5	31.4	29.5	150.0

Budget (continued):

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Improved Management						
Energy Data Base and System Modeling	3	3	4	3	3	16
Technology Assessment of Emerging Energy Systems	2	2	4	4	2	14
Evaluation Criteria for Energy Systems	2	2	1	1	1	7
Systematic Management Analysis of Alternative Energy Futures	3	5	5	5	5	23
TOTAL	10	12	14	13	11	60

B. INCREASED EFFICIENCY $1440M

Program Goals:

1. **High-Temperature Gas Turbine $315M**

To conserve energy fuels by developing high-temperature turbine systems that will result in increased efficiency of energy conversion.

2. **Advanced Cycles, Fuel Cells, and Other $210M**

To conserve energy fuels by developing more efficient methods for converting fuels to useful energy (other than through high-temperature gas turbine systems).

3. **Advanced Automotive Propulsion $300M**

To conserve energy and energy fuels by developing more efficient propulsion systems for automotive units.

4. **Rail, Bus, Ship, and Air Systems $205M**

To conserve energy by developing more efficient propulsion systems and increasing the efficiency of use patterns of air, rail, bus, and ship systems.

5. **Energy and Fuel Transmission, Distribution and Storage $200M**

To conserve energy by developing more efficient and reliable means of transmitting, distributing, and storing energy and energy fuels to meet the demand sector of the future in a safe, environmentally acceptable way.

FY 75-79 Program Objectives:

1. **High-Temperature Gas Turbines**

   a. To increase the overall efficiency and reliability of power generation and space heating systems by developing efficient high-temperature gas-turbine systems.
   b. To develop a direct cycle gas turbine for use with the high temperature gas reactor (HTGR).

2. **Advanced Cycles, Fuel Cells, and Other**

   a. To increase the overall efficiency and reliability of power generation by developing potassium-vapor topping and magnetohydrodynamic (MHD) conversion systems.
   b. To develop efficient and economical fuel cells for centralized and decentralized power generation.
   c. To develop systems for the economical conversion of wastes to power.
   d. To investigate, evaluate, and develop new concepts for efficient energy conversion.
   e. To evolve the basic constituent technologies that enable the substantial improvement of various power systems or that make feasible entirely new concepts for power generation.

3. **Advanced Automotive Propulsion**

   a. To improve the energy consumption efficiency of existing propulsion systems for autos and trucks and demonstrate new energy conservative vehicle systems.
   b. To explore and develop systems to use alternative fuels as substitutes for fuels derived from crude oil.

4. **Rail, Bus, Ship, and Air Systems**

   a. To conserve energy by improving systems capability to integrate mass transit systems.
   b. To develop design and engineering improvements to increase energy efficiency of ships.
   c. To improve efficiency of energy use by air transportation systems.

5. **Energy and Fuel Transmission, Distribution and Storage**

   a. To develop new or improved technology for a-c and d-c bulk power transmission systems that will provide the capability to double the present capacity (with further eventual increase to 4 to 10 times present capacity) economically and without environmental degradation.

b. To develop underground transmission systems capable of matching future overhead systems in both power capacity and voltage with as low a cost differential between overhead and underground as possible.
c. To improve distribution system efficiency and reliability through advanced systems security/control methods and equipment.
d. To develop efficient and environmentally acceptable methods of storing energy for use during peak energy demand periods.
e. To develop advanced ship concepts for the transportation of fuels with improved throughput and efficiency and with improved environmental and safety controls.

Contributions to the Energy System If Success Is Achieved:

1. High-Temperature Gas Turbines

Energy savings in the year 2000 will amount to 2 x 10^{15} BTU, if high temperature gas turbines can be developed. Such turbines used in conjunction with ordinary steam cycle converters could raise the conversion efficiency of central station power plants to 50% or greater.

High-temperature gas turbines directly coupled to heating system burners could produce electric power and reject the waste heat for space heating purposes. The electric power generated would be a bonus not obtained in current heating systems. Some 2 x 10^{15} BTU per year could be saved this way by 2000. A direct-cycle gas turbine operating from the helium coolant from the HTGR will reduce efficiency losses that are expected if heat exchange to a second fluid is effected.

2. Advanced Cycles, Fuel Cells, and Other

Potassium topping cycles would conserve 1 x 10^{15} BTU per year by 2000. MHD used in a topping-cycle mode would effect similar savings.

Conversion systems using wastes as fuels have an unknown effect on the energy system but represent a major potential in solving municipal (and other) waste disposal problems.

Fuels cells could be used for decentralized conversion of fuels (e.g., natural gas) to electric power in homes or buildings or used to replace peak power generating systems at decentralized locations.

3. Advanced Automotive Propulsion

The proposed transportation energy research and development program will reduce transportation dependence on crude oil by 22% in the year 1985, by 55% in the year 2000, and up to 100% after the year 2000. The proposed program for auto/trucks will result in a projected savings of approximately 1 billion barrels of oil per year by 1985 and 3 billion barrels per year by 2000.

4. Rail, Bus, Ship, and Air Systems

Information will be developed which could result in operational economics of aircraft to accomplish a 15% reduction in fuel use by 1985. The propulsion segment of the program provides means for reducing aircraft fuel requirements in the mid-1980's and beyond by major improvements in engine technology. Savings on the order of 30% or more by 2000 appear to be feasible; the proposed program will initiate the research and development effort required. The successful completion of research and demonstration projects directed toward a near-term reduction in transportation petroleum consumption by means of shifts to the energy conservative bus and rail modes of transportation could result in reducing the total projected transportation energy consumption by 3% in 1985 (0.15 billion barrels per year) and 5.8% in the year 2000 (0.36 billion barrels per year). With successful research and development, potential power savings of 15% can be made in the operation of ships.

5. Energy and Fuel Transmission, Distribution and Storage

Current technology applied to the projected need for electrical power in 1985 and 2000 would result in a doubling and quadrupling, respectively, of power lines and auxiliary facilities. The research and development objectives, if attained, would allow the transmission and distribution of the power with fewer high-capacity lines and result in underground transmission of much of the increased supply. Storage systems using batteries, electromagnetic, or mechanical devices would reduce requirements for peak load generation equipment that are inherently less efficient and make no use of the excess base load capacity during off-peak hours.

Liquefied natural gas tankers operating today lose up to 10% of their capacity through evaporation and represent significant safety hazards both on the seas and in port. Research and development would increase efficiency and mitigate the dangers. New ship concepts such as submarine tankers and extremely large barge-tankers would allow the shipment of energy fuels from arctic regions, lower costs for bulk shipment, and obviate requirements for deep-water ports for deep-draught tankers.

Program Plan:

1. High-Temperature Gas Turbine

An open-cycle high-temperature gas turbine will be developed to the point of constructing and operating a combined cycle 100-MW demonstration power plant by 1979. A variety of fuel sources must be tested for compatibility. Catalytic combustion processes, water cooling techniques, and the application of ceramic materials for blades will be included in the development program.

A high-temperature gas turbine whose exhaust is used for space heating will be developed. A 2- to 3-MW power plant demonstration unit will be constructed and tested. Following tests, several such units will be used by the Department of Housing and Urban Development for demonstration in model energy conserving housing developments.

A 750-MW(e) helium direct-cycle gas turbine facility will be constructed to develop a turbine for use with the HTGR.

2. Advanced Cycles, Fuel Cells, and Other

A preliminary design and detailed economic assessment of a 1000-MW power plant using a potassium topping cycle will define program specifications. Based on these specifications, development will proceed to include design, construction, and operation of a pilot 30-MW potassium vapor topping cycle unit by 1979.

The MHD program will accelerate the development of the open cycle, liquid-metal closed cycle, and closed-cycle plasma concepts. All three program elements will address materials questions, systems analysis, and component design.

The program directed toward tne use of wastes as fuels includes systems studies and prototype equipment development and testing for combustion, biochemical conversion and pyrolysis, and combusting wastes for power generation and auxiliary emission control technology development. Six incinerator-boiler pilot plants would be constructed or modified and operated.

Fuel cell development would be extended substantially to produce pilot and demonstration plants for acid hydrogen, methyl alcohol molten carbonate, alkaline hydrogen and high-temperature (1000°C) solid electrolyte type cells. Both centralized and decentralized applications would be studied. Pilot plants 10 kW or larger are planned.

Higher conversion efficiencies may be realized by utilizing advanced concepts such as Feher (CO_2) cycles, thermionics, or thermogalvanic cells. Applied research to test these concepts is planned in the FY 1975-1979 period.

A vigorous program of supporting research and development is necessary to augment the above program. Emphasis will be on metals and ceramics research for high-temperature application, thermodynamics, and catalysis.

3. Advanced Automotive Propulsion

Significant short-term impact can be achieved by conducting a program of research, development, and demonstration to provide a factual data base for a regulatory program aimed at reducing automotive petroleum consumption.

Assessment studies will be conducted to define the fuel economy improvements achievable with state-of-the-art technology and with new improved technology. Results will be disseminated, and development of the new technology will be initiated. Demonstrations of fuel economy improvements achievable with this technology will begin.

Several propulsion and vehicle systems will be evaluated, two of which will be brought to the engineering development phase. Preliminary battery design for a moderate performance electric car will be completed in FY 1977, and prototype motors, controls and power conditioning will be demonstrated in FY 1979. Studies will continue on the technical and economic feasibility of using fuels derived from domestic nonpetroleum energy resources for automotive transportation.

4. Air, Rail, Bus, and Ship Systems

Significant short-term impact can be achieved also by conducting a program of research, development, and demonstration to provide a factual data base for a regulatory program aimed at reducing aircraft petroleum consumption. Studies will be conducted to provide the technical basis for operational measures which will reduce near-term fuel savings on current aircraft.

Work will be done to provide the technical information required by developers of synthetic hydrocarbon fuels for assurance that the fuels, when produced, will be suitable for current aircraft propulsion utilization and to devise and demonstrate the technology for alternate fuels handling at airports.

Work will be directed toward technology for improving fuel economy of existing engine types, for development of advanced fuel-conservation gas turbine engines, low-drag aircraft, and for adaptation of aircraft gas turbine engines to the use of alternate fuels.

Some effort will be expended to determine the technical and economic feasibility and to generate critical long-lead technology for air-cushion vehicles, lighter-than-air vehicles, and very large slow airplanes as energy-conservative alternatives to conventional aircraft for large cargo shipment.

New rail and bus technology developed by industry and the Federal Government is proposed to be brought to bear in new-initiative demonstrations. Major efforts for integrated bus transit systems are proposed for a city with a population under 1,000,000 to be followed by a larger city of about 2,000,000. Computer aided information dissemination systems will be demonstrated.

Work will be done to improve those aspects of ship design and operation that impact on fuel consumption (hull shape, propeller design, and anti-fouling techniques). Work will continue on nuclear propulsion for ships, at least through the exploratory development phase.

5. **Energy and Fuel Transmission, Distribution and Storage**

Development objectives during the FY 1975-1979 period include prototype 1100-kV a-c overhead transmission lines and a 100-MW d-c terminal demonstration project. Four improved types of underground cables will be developed and completed for commercial use, and model tests of superconducting cables will be conducted.

A 10-MWH pilot model of a sodium-sulfur or lithium-sulfur battery will be built and a superconducting energy storage magnet will be developed to the prototype design stage. Engineering development of a flywheel facility will be completed.

Concept designs of surface and underwater ocean tankers, especially adapted for arctic service, will be completed. Advanced designs for LNG tankers with greater efficiency and safety will be developed. Computer controlled sailing ships will be studied and scale models tested.

Supporting Evidence:

1. **High-Temperature Gas Turbines**

Although gas turbines are now used widely, the use of gas turbines in sizes required for central station base load power production is rare, and lifetimes are too short to justify economic operation. Conservative management policies within the utility industry retards acceptance of this innovation and market formation. Large scale demonstration is necessary to encourage adaption to commercial use. Research and development partnership with industry should be forthcoming.

2. **Advanced Cycles, Fuel Cells, and Other**

Potassium topping cycles are technically feasible, but several materials problems must be overcome before systems can be built that will operate for lifetimes required in central power stations. Progress on MHD systems is also materials dependent.

Wastes used as fuel is also a technically feasible concept, but the economics of such an industry will depend largely on total system design to include recovery of other valuable resources (e.g., metals). Cost analyses and total system demonstration are required for proof of the concepts.

Fuel cells work today, but capital costs are high. Their ultimate application may depend on plentiful supplies of natural or synthetic gas or hydrogen. Less expensive catalysts and mass production methods may hold the key to reducing high initial costs.

Advanced concepts such as Feher (CO_2) cycles, thermionics, and thermogalvanic conversion are still in the early stages of technical evaluation.Theoretical efficiencies are high (60% or greater) but much bench scale testing is required to prove concepts for eventual economic application.

3. Advanced Automotive Propulsion

There seems to be no insurmountable manpower or capital availability problems in developing greater efficiency in automotive engine design and operation. Certain engines including the Rankine and Stirling cycle engines are inherently more efficient than the present internal combustion engine, and it should be possible to adapt one of these for future use on automotive systems.

Widespread application of new designs or concepts must be preceded by industrial willingness to change long standing methods of operation or governmental sanctions.

4. Air, Rail, Bus, and Ship Systems

Aircraft turbines are relatively efficient at present, but large savings in fuel can be achieved through improvements in the national air use system. Similarly, it is imperative that much thought be given to shifting transport modes from relatively inefficient automotive and air systems to the more inherently efficient rail system. The use of nonpetroleum fuels for aircraft systems would effect a significant savings in crude-oil requirements.

While ocean transport is still the most economical form of cargo shipment, there remain significant impediments to greater efficiency, specifically in drag reduction.

Nuclear ships exist today, but the economics of wider commercial use must be studied further, demonstrated, and safety aspects proven.

5. Energy and Fuel Transmission, Distribution and Storage

Cost restrictions inherent in underground transmission systems and superconducting magnets may require Federal tax incentives initially. No other restrictions in development or operating skills, material, or equipment are preemptive. Transmission systems with larger capacity are technically feasible, but economic criteria demand further development for cost-reduction purposes.

Storage systems must show economic advantages over peak-load generating costs that are now incurred.

The potential for finding and exploiting significant quantities of fuels in the arctic regions demands that we investigate appropriate means for economic and safe transport of those fuels to U.S. markets.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
High-Temperature Gas Turbines	18.3	66.8	79.3	76.8	73.8	315.0
Other						
Potassium Topping Cycle	7.0	14.5	26.0	20.5	22.0	90.0
Wastes as Fuel	1.5	2.6	2.3	1.9	1.7	10.0
Fuel Cells	5.5	9.5	17.0	21.0	27.0	80.0
Advanced Concept	2.0	2.0	2.0	2.0	2.0	10.0
Enabling Technology	2.0	3.0	5.0	5.0	5.0	20.0
Subtotal	18.0	31.6	52.3	50.4	57.7	210.0
Advanced Automotive Propulsion	53.0	59.0	59.0	71.0	58.0	300.0
Air, Rail, Bus, and Ship Systems						
Air	10.0	19.0	26.0	30.0	54.0	139.0
Rail & Bus	4.0	5.3	6.3	9.0	10.4	35.0
Ship	6.0	8.2	4.2	5.8	6.8	31.0
Subtotal	20.0	32.5	36.5	44.8	71.2	205.0

Budget (continued):

	Dollars in Millions					
	1975	.1976	1977	1978	1979	Total
Energy & Fuel Transportation Distribution & Storage						
Overhead T&D	8.1	7.4	7.4	7.4	9.4	39.7
Underground T&D	5.3	7.5	7.8	10.0	12.0	42.6
Storage	4.2	7.0	11.7	12.5	15.5	50.9
Systems Research	2.4	3.6	4.0	2.9	3.9	16.8
Ship Delivery System	7.0	8.0	9.0	12.0	14.0	50.0
Subtotal	27.0	33.5	39.9	44.8	54.8	200.0

TASK 2—INCREASE PRODUCTION OF OIL AND GAS

A. PRODUCTION $310M

Program Goal:

To increase the production of oil and gas by developing and demonstrating new technologies and extending current technologies that will result in rapid and economic in situ recovery of domestic resources.

FY 75-79 Program Objectives:

1. To increase the production of oil in operating fields by developing and demonstrating methods for secondary and tertiary recovery of residual reserves.
2. To increase the production of oil and natural gas by developing and demonstrating methods for stimulating flow in low permeability reservoirs.
3. To increase the production of synthetic petroleum from oil shale by developing and demonstrating methods for processing oil shale in situ to recover liquid products.
4. To increase the production of oil and gas by developing and demonstrating equipment design and methods of operation that will result in more economical drilling operations, environmentally sound practices, and a concomitant rise in find rates and the exploitation of deeper reservoirs.

Contributions to the Energy System If Success Is Achieved:

It is estimated that secondary and tertiary recovery could increase the production in operating fields by 260 million barrels per year by 1985. This could also result in the production of an additional 700 billion cubic feet of associated natural gas per year by that time. Improved methods for stimulating the flow of oil and natural gas in low permeability reservoirs could result in recovery of an additional 70 million barrels of oil and 2.6 trillion cubic feet of natural gas per year by 1985. Sucessful development of the technology for processing oil shale in situ could result in the production of 200 million barrels of synthetic oil per year by 1985. The development of equipment and procedures for faster, deeper, and more economical drilling could result in the discovery and recovery of 500 million barrels of oil and 2.5 trillion cubic feet of natural gas per year by 1985. Better drilling and operating policies could reduce the incidence of oil spillage and make offshore operations more environmentally acceptable.

Program Plan:

Combinations of four methods for secondary and tertiary recovery of oil will be tested in approximately 20 experiments that will include some 15 reservoir types. These experiments will determine optimum methods applicable to particular reservoirs.

Seven experiments are planned in three different reservoirs to determine the potential of massive hydraulic fracturing and chemical explosive fracturing for stimulation of low permeability formations. One further nuclear stimulation demonstration is also planned. The program is designed to determine which stimulation technique or combination of techniques is most suitable for given reservoir characteristics.

In situ retorting of oil shale will be tested in the Rocky Mountain basins using a combination of several different fracturing techniques and retorting conditions. The recovery rates for each combination and the control problems encountered will be studied to determine optimum technical design.

Development will be continued on jet drilling techniques and equipment and spark cavitation drilling concepts. Field tests on prototype equipment are planned to determine what improvements are possible in rate of penetration and capabilities in differing rock formations. Better control devices and practices will be tested to show potentials for reducing oil spillage, and oil-spill cleanup methods will be assessed.

Supporting Evidence:

Oil company research on secondary and tertiary recovery has been significant (~\$30M/year). The lack of data exchange has inhibited widespread application of techniques or development of techniques with more general application. A Federal effort should be capable of drawing the technology base together and effecting technology transfer.

Nuclear stimulation of tight gas reservoirs has been successfully demonstrated. Further testing is required to demonstrate economics and to enhance efficiency. Explosive and hydraulic fracturing is effective in certain reservoirs, but massive techniques are theoretically indicated for effectiveness in the tight reservoirs.

In situ oil-shale retorting has been successfully demonstrated on a pilot scale.

Faster experimental drilling techniques now exist. Improvements are required in control technology, downhole equipment developments, and in extending operating lifetimes. "Blowout" control and oil-spill cleanup development are continuing activities of the oil industry but require greater emphasis to support enlarged offshore drilling activities.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Secondary and Tertiary Recovery (fluid injection)	10.7	22.4	20.5	12.0	4.8	70.4
Stimulation (conventional and nuclear)	9.1	31.2	23.2	16.6	16.2	96.3
Oil Shale In Situ (conventional and nuclear)	9.3	30.0	30.7	29.6	28.2	127.8
Advanced Drilling	2.6	5.5	5.1	1.3	1.0	15.5
TOTAL	31.7	89.1	79.5	59.5	50.2	310.0

B. RESOURCE ASSESSMENT $150M

Program Goal:

To support the increased production of oil and gas, the substitution of coal for oil and gas, and the production of nuclear fuels by enlarging the qualitative and quantitative inventory of domestic resources through exploratory techniques and new equipment and methods research.

FY 75-79 Program Objectives:

1. To improve as rapidly as possible the knowledge level of domestic resources and economically available reserves of oil and gas, both onshore and offshore.
2. To improve as rapidly as possible the knowledge level of domestic resources and economically available reserves of uranium and thorium.
3. To assess the Nation's coal resources in terms of quality, regional distribution, and recoverability.
4. To improve the information base on the distribution and quality of oil shales and tar sands.
5. To maintain an overview of the quantities and availability of nonenergy mineral resources essential to the energy-producing system.
6. To improve general exploration theory and technology.

Contributions to the Energy System If Success Is Achieved:

This research and development will lead not only to knowledge of new resources but also to better ability to judge the quality of existing resources. In coal especially this will lead to the ability to do better other research on combustion (which is related to the by-product content of coal types). In the oil-shale area it will also better define sites for in situ plants.

Program Plan:

Program activities would comprise 70% research in preexploration assessment technology and 30% analysis and research in exploration technology for onshore resources; and 90% exploration and 10% analysis and research for offshore resources.

Preexploration assessment to include the use of novel techniques will enlarge the data base necessary to analyze regions where resources are expected. The analysis effort will consist of accumulating, collating, and assessing data to improve methods of determining resource availability, both quantitatively and qualitatively.

The research effort is largely directed at the development of new exploration and analytic tools needed to locate and assess new reserves, including analogic digital modeling of energy resource deposits and identification of sedimentary process indicators for exploratory work.

A viable technology transfer program is required to disseminate findings to industrial users who would conduct most actual exploration efforts.

Supporting Evidence:

Federal responsibility for the development of natural resources cannot be properly discharged without knowledge of the resource base. Determination of viable energy options, resource development priorities, public land lease programs, prices, and subsidies should be based on reliable evidence of resource availability.

The current Federal research and development resource assessment program is not considered adequate to support a vigorous expansion in the use of domestic resources. Rational development at an increased pace requires greater knowledge than now exists if the highest payoff at least cost and environmental risk is to be ensured.

Industry welcomes and relies on Federal data and analyses to design their exploration and exploitation programs. Further, such data and analyses will provide a more rational basis for the development of national energy policies and energy research and development programs.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Petroleum and Natural Gas	6.7	8.3	13.0	20.0	22.0	70.0
Uranium and Thorium	6.3	6.7	8.0	9.0	10.0	40.0
Coal	3.0	4.0	4.5	4.5	4.0	20.0
Oil Shale	1.0	1.0	1.0	1.0	1.0	5.0
Non-Fuel Resources	1.0	1.0	1.0	1.0	1.0	5.0
General Exploration Technology	2.0	2.0	2.0	2.0	2.0	10.0
TOTAL	20.0	23.0	29.5	37.5	40.0	150.0

TASK 3—SUBSTITUTE COAL FOR OIL AND GAS

Program Goal:

1. **Mining** $325M

To develop and demonstrate more productive, safe, low environmental impact coal mining technology to the point where the mining industry can rapidly incorporate this technology in greatly expanded future operations.

2. **Direct Combustion** $200M

To substitute coal for oil and gas by developing coal-fired boilers for electric power generation which have improved thermal conversion efficiency, reduced costs, and acceptable environmental impact.

3. **Synthetic Fuels** $1270M

To substitute coal for oil and gas by developing the technology for converting coal to clean liquid and gaseous fuels.

4. **Common Technology** $380M

To provide the necessary supporting research and development to achieve the other coal objectives and to develop the technology necessary for reducing, to acceptable levels, the environmental impact of commercial scale coal processing, transportation, conversion, and combustion operations.

FY 1975-79 Program Objectives:

1. **Mining**

   a. To develop and demonstrate surface coal mining systems featuring integrated extraction and reclamation processes that meet environmental, social, and economic constraints.
   b. To develop underground coal mining systems that increase average productivity to 30 tons/man shift with as complete extraction as possible in a manner that ensures safety and environmental protection.
   c. To develop systems for mining oil shale in an environmentally safe and productive manner.

2. **Direct Combustion**

To complete pilot-scale tests of four methods of clean combustion of coal and to build and operate one pressurized fluidized-bed boiler system.

3. **Synthetic Fuels**

   a. To investigate several processes for converting coal to pipeline-quality gas and to build and operate a demonstration coal gasification plant.

b. To build and operate three to five pilot plants and two combined-cycle demonstration plants to test four processes for converting coal to gas of a low BTU content.

c. To investigate several processes for converting coal to liquid boiler and distillate fuels, select three or more of these for further testing in pilot plants, and design one demonstration plant.

d. To support the construction of two commercial-scale plants incorporating state-of-the-art processes and techniques for producing oil and gas from coal and to measure, monitor, and evaluate the operation of these plants.

4. Common Technology

a. To obtain data through laboratory research on materials and component development for various coal conversion processes.

b. To provide exploratory data for development of new processes.

c. To develop an economical method of removing sulfur dioxide from flue gas.

d. To reduce impurity and pollutant discharges resulting from the combustion of coal.

e. To improve the technology for impurity removal from coal by physical and chemical treatment.

f. To ensure the environmental acceptability of commercial scale processes of converting coal to gas and to liquids.

g. To develop economical methods of disposing of wastes resulting from the use of coal.

h. To investigate the feasibility of converting coal to gas in situ.

Contributions to the Energy System If Success Is Achieved:

1. Mining

To attain energy self-sufficiency, U.S. coal mining capability will have to at least triple in this century. In the near-term over 600 million tons/year of additional coal production capacity will be required by 1985.

2. Direct Combustion

When fluidized-bed boilers are developed, they will capture at least 25% of the market for new coal boilers. This implementation rate would result in 300 MW (or 0.2×10^{15} BTU fuel input) installed capacity in 1985 and 40,000 MW (2.2×10^{15} BTU) in the year 2000.

3. Synthetic Fuels

As a result of the proposed program, full-scale (250 million cubic feet/day) high-BTU gasification plants could be operating by 1980. Present estimates point to 1.2 trillion cubic feet/year of high-BTU natural gas from coal by 1985 and 3 trillion cubic feet/year by 1990.

Commercial production of low-BTU gas is expected to proceed at a rapid pace after successful demonstration, and the estimated benefits of this program to the Nation are:

	1985	2000
No. plants	10 commercial plants	210 commercial plants
Electric power	32.9 x 10^6 MWH(e)	1150 x 10^6 MWH(e)
Q energy released for priority uses	0.28 x 10^{15} BTU	9.8 x 10^{15} BTU
Q saved by high efficiency	0.014 x 10^{15} BTU	0.49-0.9 x 10^{15} BTU

Coal liquefaction could produce 250,000 barrels/day of liquid fuels in 1985. By the year 2000 it could produce 3 to 4 million barrels/day of liquid fuels and 1.5 trillion cubic feet of by-product synthetic pipeline gas.

4. Common Technology

Flue-gas cleaning and fuel cleaning could ultimately impact upon the entire industrial, residential/commercial, and utility market. Flue-gas environmental control capabilities could be achieved on 10 to 16 x 10^{15} BTU of generating capacity by 1985 and 20 to 40 x 10^{15} BTU of generating capacity by 2000. By the year 2000, yields of 2 to 6 x 10^{15} BTU/year of clean usable energy could be obtained by fuel cleaning. Ultimate application of pollution control technologies will allow achievement of air quality criteria from fuel combustion and, thus, continued use of existing domestic coal as fuel.

In situ gasification of coal could produce large quantities of pipeline-quality gas without recourse to mining and the disposal of processing-plant wastes.

Program Plan:

1. Mining

The surface coal mining program will develop and demonstrate mining and reclamation systems and equipment that would permit surface mining in the western and Appalachian coal fields at minimum cost and environmental impact. Particular attention will be paid to demonstration projects to assess the efficacy of the best present technology and identify and resolve indicated deficiencies.

The underground coal mining program will develop and conduct demonstrations of equipment systems for high-speed horizontal mine development, improved longwall mining, continuous materials handling systems, improved roof control systems, commercial extraction of methane from virgin coal and gob areas, and novel mining concepts. Technology for environmental protection associated with underground mining, including control of subsidence phenomona, control of chemical mine drainage effluents, and acceptable methods of waste disposal will be demonstrated.

The shale mining program is directed toward heading off immediate critical problems in oil-shale mining in the Piceance River basin, Colorado, where mining may be greatly increased soon. Principal emphasis will be on: (1) systems analysis effort to adapt surface mining technology to the unique problems of large-scale oil-shale extraction; (2) the development of basic structural parameters for the design of underground mines; (3) investigation of occurrence and movement of groundwater in the oil-shale strata; and (4) investigation of environmentally acceptable means of restoring surface-mined terrain to as good or better than original condition. New facilities will include a multipurpose prototype mine shaft to provide access to the deeper oil-shale sections.

2. Direct Combustion

Several clean combustion processes will be developed and tested in pilot plants. These include: (1) the pressurized boiler concept, in which the fluidized bed contains the heat transfer surface and the hot pressurized off-gases are expanded through a gas turbine; (2) the atmospheric pressure concept; and (3) the direct turbine drive concept. A mathematical model describing the fluidized-bed combustion process will also be developed. Each of the three variations will be tested in a separate intermediate sized plant (30 to 50 MW). One full-scale demonstration plant will be built.

3. Synthetic Fuels

The proposed plant for high-BTU gasification involves the acceleration of the present program being conducted under the joint direction of the Office of Coal Research and the American Gas Association, and the present Bureau of Mines program, as well as a program of supporting research and development for equipment/materials research and development and for basic studies of gasification chemistry. This plan includes the operation of the Hygas process pilot plant and the CO_2-Acceptor process pilot plant, completion of the construction and operation of pilot plants for the Synthane and Bi-Gas processes, and the construction and operation of one 80 million cubic feet/day demonstration plant.

The low-BTU gasification program includes the construction of the entrained bed gasifier type pilot plant [30 MW(e) to 50 MW(e)] within an existing utility and consisting of a gasifier, a gas turbine, a waste heat boiler, and a steam turbine. Cycle efficiency is estimated to be over 40% with initial operation expected in 1977. A fluidized-bed gasifier (pressure type) pilot plant [30 MW(e) to 50 MW(e)] will also be constructed. Initial operation is planned for 1978. A slurry fired pilot scale plant is planned for initial operation in 1976 or 1977. This is a pumpable coal/water high-temperature slurry feed system with high-temperature clean up of sulfur and particulates in a single compact vessel. In addition, three to five of the numerous new concepts for low-BTU gasification will be tested at the pilot scale.

Supporting development, including hot gas cleanup projects, will be carried out. Approximately two-thirds of the funding will be for the two demonstration projects and one-third for the smaller scale projects.

The coal liquefaction program consists of a series of interrelated, mutually supporting projects that will investigate alternate methods to liquefy coal. The work includes appropriate pilot plant, process plant, and laboratory-scale experiments. The end result is expected to be a demonstration plant test center where synergistic processes can be tested singly and in combination to show both technical feasibility and economic viability. A solvent refined coal (SRC) pilot plant will be completed and put in operation.

In addition, it is planned to support industry initiatives in funding the construction of two commercial scale plants to produce synthetic fuels from coal using state-of-the-art processes and technology. The operation of these plants will be monitored and evaluated to determine engineering improvements needed to upgrade processes and to assess the potential for further research and development in coal conversion processes.

4. Common Technology

Although the basic feasibility of producing gas and oil from coal and shale has already been demonstrated, ultimate economic practicality of these energy sources may depend either on the development of new procedures for at least part of these processes or on the gradual improvement of existing processes, materials, and equipment. Specific areas where technology development and support research are needed include: equipment development, materials improvements, investigation of catalysts and chemical kinetics for conversion processes, process development, and hydrogen production.

Methods for ensuring the environmentally acceptable combustion and utilization of domestic fuels will be reduced to commercial practice. Processes will be developed and demonstrated for improved control of particulate, sulfur dioxide, and hazardous pollutant emissions from combustion flue gases. Methods for environmentally sound coal conversion will be reduced to commercial practice. Technology for the physical and chemical separation of pollutant-forming constituents from coal will be demonstrated. Methods for ensuring the environmental integrity of major conversion technologies will be developed, and conversion process by-product recovery/utilization will be developed.

Concepts for the in situ gasification of coal will be evaluated and tested on a small scale to determine the potential for producing synthetic gas without recourse to mining and surface processing, thus reducing the overall environmental impact.

Supporting Evidence:

1. Mining

A resource base of necessary research skills exists within the Government owing to existing programs in the Bureau of Mines and Geological Survey. Lead time exists in which to develop skilled manpower for implementation of research results. Union resistance to improved mining systems can be expected to be minimal because of historical union positions, benefits to the miners, and the importance of the energy crisis. The importance of the crisis will also affect potentially inhibiting legislative restrictions. As the economic incentive (a long-term requirement for coal) increases, the coal industry will be able to adapt its financial and management structure to the necessary capital expenditures for innovative mining techniques. The same should hold true for the mining equipment industry.

2. Direct Combustion

Much of the technology in this area is available on a laboratory-scale basis. Further engineering and development is required to demonstrate its use on a commercial scale.

3. Synthetic Fuels

Several methods are known for producing pipeline quality and low-BTU gas from coal on a laboratory scale. The program described will allow further larger scale testing of these processes and the completion of a demonstration plant. The coal liquefaction program is based on technology that has been carried through small scale equipment and is supported by ongoing pilot plant projects. The primary risk involves scale-up, which means that plant outputs cannot be guaranteed but product quality can. The primary barrier to commercial acceptance is industrial fear of the magnitude of the investment in commercial plants. By underwriting the major risk, the Government will ensure the maximum rate of commercial adoption of these processes.

4. Common Technology

The various processes for burning and converting coal could not be pursued economically or rationally without parallel technology development and supporting research. Government funding of the pollution control area is required in view of the requirement for a cohesive, well-directed research and development program to support environmental quality control. Private industry cannot be relied upon to develop the broad research and development program that is needed.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Mining	45	57	64	77	82	325
Direct Combustion	30	35	40	44	51	200
Synthetic Fuels	240	287	264	254	225	1,270
Common Technology	90	72	66	72	80	380
TOTAL	405	451	434	447	438	2,175

TASK 4—VALIDATE THE NUCLEAR OPTION

A. HTGR, SAFETY, WASTE MANAGEMENT, ETC. $1245.7M

Program Goal:

To guarantee the nuclear option by performing research and development that will enhance the safety, environmental acceptability, reliability, and economic viability of nuclear converter reactors.

FY 75-79 Program Objectives:

1. To develop an improved basis for assessing the performance of safety systems and to develop improved safety systems and surveillance instrumentation necessary to ensure the safe and reliable operation of nuclear power plants.
2. To develop the control technology necessary to reduce nuclear power industry effluents to the lowest practical levels and to develop to full scale use a safe and efficient means for disposing of wastes generated by the nuclear power industry.
3. To develop techniques to reduce the environmental impact of thermal discharges from power plants and to develop guidelines for more rapid and standardized procedures for selection and review of facility sites.
4. To develop more efficient methods for uranium isotope separation.
5. To conduct research and development needed to heighten assurance of safe, reliable operation of the HTGR.
6. To develop satisfactory fuel fabrication and reprocessing systems for thorium to be used in the HTGR.
7. To successfully demonstrate the Light Water Self-Sustaining Reactor.

Contributions to the Energy System If Success Is Achieved:

The program proposed will ensure that nuclear power plants are available to meet their planned share of the requirements imposed by the growth in demand over the next few decades. Nuclear reactors are now used to generate 5% of the Nation's electrical power. This fraction is expected to grow to about 23% by1980, 49% by 1990, and 60% by the year 2000.

The program is directed at ensuring that the technology and resources are provided at the appropriate times to meet these scheduled increases in the role of nuclear power. It is also directed at ensuring that current apprehensions about the safety of nuclear power are met by definitive research and development at an early time.

The HTGR and the light water self-sustaining reactor can more efficiently and economically utilize available uranium and thorium resources and reduce the uranium supply and separative work requirements per unit of power over plant life. This will make sizable contributions toward conserving resources.

Program Plan:

Theoretical and experimental investigations will be conducted to obtain more complete information as to component failure and accident probabilities for nuclear reactors. Practical experimental results will be derived from the Loss of Fluid Test Facility (LOFT). The investigations will yield additional data applicable to the design and engineering of safety features and the establishment of regulatory standards.

The design of an engineered waste storage facility will be completed and construction begun early in the five-year period. Studies will continue on disposal of long-lived radioactive wastes in geologic formations, and a pilot facility in bedded salt will be constructed. Ancillary solidification processes will be developed and tested. Development will continue, and pilot and demonstration plants will be constructed to reduce or eliminate krypton, tritium, and transuranic components from reactor and reprocessing effluents.

The concept of the dry cooling tower to replace wet cooling will be the subject of a joint government-industry technology demonstration in Wyoming. Results and other studies are expected to lead to the construction and operation of a larger scale test facility after 1980.

A significant effort will be directed towards enlarging the options for siting of nuclear facilities.

The search for more efficient processes for uranium enrichment will include development aimed at improving the gaseous diffusion process, the demonstration of commercial feasibility of the gas centrifuge process, and exploratory efforts to prove technical feasibility of isotope separation using lasers. The Centrifuge Test Facility and ancillary facilities will be completed.

The base program for the High Temperature Gas Reactor (HTGR) will continue development of components and the review of safety features. The completion of research and development for ^{233}U-thorium utilization in the HTGR will include the completion and operation of reprocessing and refabricating pilot plants. Process demonstrations will open the path to using large resources of thorium in addition to ^{238}U.

An experimental core for a self-sustaining light water reactor using the ^{233}U-thorium fuel cycle will be tested in the AEC's Shippingport facility.

Supporting Evidence:

The current problem is to ensure timely licensing for construction and operation of nuclear power plants. One of the most important near-term objectives in this regard is to provide further assurance of the safety of the water and gas-cooled reactors. A considerable expansion of the reactor safety program needs to be undertaken to resolve questions raised. A related question concerns the management of highly radioactive wastes. A final solution to this problem is probably not necessary in the near-term period, but study and evaluation of several potential waste-management methods can result in the selection of the most promising interim and permanent disposal techniques. There must be sufficient assurance given that the present and proposed handling of these wastes is not only satisfactory for the time being but also that the methods used will not place undue burdens on future generations.

One of the principal problems will be finding suitable locations for nuclear power plants. About 50 sites have now been approved, and it is becoming difficult in some cases to locate new sites that meet AEC site criteria for safety, are available, and can supply water coolant needs. A program on dry cooling towers is included that will increase site selection possibilities by reducing the need for access to large amounts of cooling water. The efficiency of the electrically generated power will be about 10% lower when dry cooling towers are used, but success of this technical innovation will overcome a difficult siting problem. Coupled with development of efficient cryogenic transmission methods, use of dry cooling towers will permit clustering of power reactors in parks in remote areas of the country, where population density is low and land costs are less significant.

A determined production program will be required to prevent shortages of nuclear fuel over the period before the breeder is heavily relied on. Additional uranium isotope separation capacity must be provided, with construction begun in the next two years if the enriched-uranium requirements of the 1980s are to be met. Planning now for improvements in isotope separation will ensure an adequate and low-cost capability.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Reactor Safety, Reliability, and Performance	90.6	125.6	143.0	170.5	189.5	719.2
Uranium Enrichment	64.2	54.8	57.4	58.4	59.4	294.2
High-Temperature Gas Reactor	40.0	44.7	24.2	26.9	28.0	163.8
Light-Water Self-Sustaining Reactor	21.4	17.7	9.8	9.8	9.8	68.5
TOTAL	216.2	242.8	234.4	265.6	286.7	1,245.7

B. BREEDER REACTORS $2844.3M

Program Goal:

To guarantee the nuclear option by developing a safe, environmentally acceptable, and economically successful breeder reactor that will draw upon domestic resources to provide an alternative long-term energy supply.

Program Objectives:

1. To develop the technology for and demonstrate the commercial feasibility of the liquid metal fast breeder reactor (LMFBR).
2. To resolve the principal design and engineering problems of breeder reactors.
3. To develop the technology and methodology necessary to resolve safety questions affecting breeder reactor design.
4. To develop the necessary technology, methods, and procedures for handling and transporting plutonium.
5. To develop the technology for alternative breeder concepts including the gas-cooled fast reactor (GCFR) and the molten-salt breeder reactor (MSBR).
6. To develop advanced technology that would result in improved utilization of fissile resources.

Contributions to the Energy System If Success Is Achieved:

Liquid metal fast breeder reactors will begin to assume an important role by the 1990s and will displace the light-water reactors as the principal nuclear plant by the early part of the next century. The breeder will be a more efficient electric generating plant thereby reducing thermal discharge to the environment and making more than 50 times greater utilization of uranium as a fuel source. By the year 2000, breeder reactors could be providing more than 250,000 MW(e) to our electrical system which would be the equivalent of about 13×10^{15} BTU thermal input. The gas-cooled fast reactor, although significantly behind the LMFBR in the developmental schedule, is a potential alternate to the LMFBR, and, if warranted, commercial operations could begin in the early 1990s.

Program Plan:

A comprehensive LMFBR technology effort is being conducted which includes support of: (1) the Fast Flux Test Facility required to conduct necessary fuels and materials testing programs and to demonstrate the performance of components selected for LMFBR use, and (2) an LMFBR demonstration plant program.

The LMFBR base program includes the continued development of fuels and investigation of their behavior properties under different conditions and with increased knowledge of the physics of breeder cores. Extensive work will be accomplished on the development of new components and the analysis of the total reactor system incorporating selected designs. The base program also includes support for the operation of the Experimental Breeder Reactor and the Liquid Metal Engineering Center.

The engineering and safety aspects of the LMFBR program will include the construction and operation of an LMFBR engineering facility and advanced fuels laboratory, a steam generator test facility, a safety test facility, and a transient safety test facility. Technology development for handling, transporting, and containing plutonium will continue toward establishing the most desirable methods and procedures for adoption as standards and to resolve public questions regarding safety.

The program for the GCFR would provide required technology on fuel and reactor core development, physics, critical assembly tests, and safety analyses. In the MSBR area a fairly low level of effort will be expended to reevaluate the economics of this concept in light of recent information on fuel costs.

Advanced technology research is planned to develop new breeder fuels and materials that can increase the breeding ratios and power ratings and decrease the conservatism presently required in breeder designs. Also, neutron cross-section information needed for the design of fast and safe test reactors will be developed.

Supporting Evidence:

Adequacy of the manpower resources to meet the research and development program will have to be planned and programmed. There is presently a surplus of technical personnel suited to the research and development program. Beyond the first two years, additional trained technical manpower will be needed in scientific and engineering disciplines. These will have to come from the universities. The requirements are within the peak supply capability of engineering schools. Availability of manpower should be no problem if measures are taken to ensure vigor of the educational programs during the intervening period.

The availability of fuel should not present any problems but will require careful monitoring and management during the expansion of the first-generation nonbreeding reactors and plutonium recycle employment. Operation of breeders in the early years will require additional uranium supplies, but, as newly bred fuel becomes available, the demands for uranium will decline relative to continuation of a light-water reactor economy.

Capital costs of breeder reactors must be kept within a range that does not greatly exceed current reactor capital costs so that the fuel cost savings realized by breeders will be sufficient to permit total power generation costs to be lower for breeders.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Liquid Metal Fast Breeder	477.0	538.6	510.8	524.2	506.0	2,556.6
Gas Cooled Fast Breeder	17.0	23.0	29.0	33.0	38.0	140.0
Advanced Technology	21.5	24.5	30.5	34.0	37.2	147.7
TOTAL	515.5	586.1	570.3	591.2	581.2	2,844.3

TASK 5–EXPLOIT RENEWABLE ENERGY SOURCES

A. FUSION $1450M

Program Goal:

To guarantee the nuclear option in the long range by developing the technology necessary for a fusion reactor to provide an inexhaustible, economically competitive, inherently safe, and environmentally acceptable supply of energy for domestic consumption.

Program Objectives:

1. To conduct theoretical, computational, and experimental studies in the body of knowledge that predicts the behavior of thermonuclear fusion experiments and the operating characteristics of fusion reactors.
2. To develop the technology necessary to perform fusion research.
3. To investigate, develop, and establish the feasibility of low-density closed (tokamak), high density closed (theta pinch), and open (mirror) magnetic confinement systems as a basis for practical fusion power generation.
4. To investigate, develop and establish the feasibility of laser fusion as a basis for practical fusion power generation.
5. To develop the engineering base, qualify materials, develop components, and conduct engineering studies necessary for the design, construction, and operation of prototype, demonstration, and commercial fusion power reactors.

Contributions to the Energy System If Success Is Achieved:

Fusion power systems are being developed primarily for electric power generation. Since the fuel supply for fusion is effectively infinite and its safety and enviromental features are very attractive, fusion power reactors could eventually become the primary source of electric power for the United States.

Because fusion power plants have the potential for high-temperature operation, they would be attractive for combining with industrial and municipal systems that could utilize the rejected heat. Examples of potential applications are numerous: basic manufacturing processes, water desalination, mineral and fossil fuel processing, space heating, and air conditioning, to name a few.

The commercialization of fusion power reactors would occur at the time of the successful operation of a fusion demonstration reactor. The goal of the projected program is to begin operation of this system by 1995.

Fusion reactors could be producing commercial electric power in the first decade of the next century and by 2020 could add 18×10^{15} BTU of energy input to our electrical system.

Program Plan:

The research subprogram will develop the knowledge to predict the performance of plasma-confinement experiments and the operating characteristics of fusion power reactors. In order to support the theoretical proving research, it will require extensive application of centralized dedicated computer facilities with an integrated network of remote job processing terminals. Theoretical studies of fusion-relevant plasmas in various confinement configurations are necessary to understand the equilibrium, stability, and transport properities of the plasmas. Experimental work on plasma production and heating, along with instrumentation development for plasma measurements, are among the earliest projects.

The development subprogram will provide the technology to plan or conduct plasma experiments. The magnetics subprogram requires very large, superconducting magnets to produce large volume, high magnetic fields to confine and stabilize fusion plasmas. The heating program will emphasize the development of neutral-beam injections for heating and/or fueling tokamak and mirror plasmas. The advanced design activity provides for the definition of conceptual designs and cost estimates for experiments prior to fabrication. Other development-activity objectives include energy storage devices, direct energy conversion, and components to support the various testing programs.

The present plan for plasma confinement systems development utilizes three principal magnetic confinement concepts. These are low-density closed systems (principally the tokamak), high-density closed systems (theta pinch), and open systems (magnetic mirror). The construction and operation of seven new facilities to test plasma shapes, neutral-beam heating, scaling, and improved confinement will be undertaken.

The technology subprogram deals with the problems that need to be solved for prototype, demonstration, and commercial fusion power reactors. Included are materials studies to determine the effect of 14-MeV neutrons and other high-energy particles on material performance, radiation environment simulation to create a simulated fusion reactor environment in which materials and components can be tested, and system studies to provide guidance. Other areas covered include major parts of the heat transfer system and the engineering base needed for the design and construction of such subsystems. Examples are neutronics, plasma engineering, coolants, blankets, shielding, tritium handling, and instrumentation.

The laser fusion subprogram will build on the theoretical base established in the military oriented laser fusion program. Projected achievement sequence is: (1) an experimental demonstration of significant thermonuclear burn; (2) the experimental demonstration of scientific breakeven for the laser fusion concept; and (3) the conduct of some reactor design studies throughout the program.

Supporting Evidence:

Although controlled thermonuclear fusion has yet to be technically demonstrated, recent program successes indicate high probabilities of success in being able to initiate and sustain fusion reactions. This factor warrants emphasis in fusion research and development.

Based on previous experience with nuclear reactors, it is clear that a savings of several years can be realized if reactor technology is developed now, assuming technical feasibility of the fusion reaction.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Research	43	52	47	70	44	256
Development	20	26	37	46	55	184
Confinement	59	113	122	153	194	641
Technology	13	39	55	69	83	259
Laser Fusion	10	20	25	25	30	110
TOTAL	145	250	286	363	406	1,450

B. SOLAR ENERGY $200M

Program Goal:

To exploit the sun and wind in order to provide a renewable, economically competitive, and environmentally acceptable energy supply for domestic consumption.

FY 75-79 Program Objectives:

1. To determine, through pilot applications, the effective use of solar thermal energy for heating and cooling of buildings.
2. To effectively use solar thermal energy for electric power generation through operation of a pilot plant [10 MW(e)].
3. To effectively use wind power for electric power generation by construction and operation of individual windmills [>100 kW(e)] and a windmill farm [10 MW(e)].
4. To determine the technical feasibility of producing electric power from ocean thermal gradients by laboratory-scale testing of prototypes and full-scale testing of necessary components.
5. To determine the capability to produce economically competitive photovoltaic cells by laboratory experimentation and development of mass production concepts.

6. To demonstrate, by pilot plant operation, the economic feasibility for conversion of wastes to fuels and the use of biota as fuel for power plant operation.

Contributions to the Energy System If Success Is Achieved:

Solar energy is virtually inexhaustible and is inherently clean. Successful research and development should ultimately lead to the capability to reduce the demand for fuels and power to heat and cool homes and commercial buildings by 30%.

Solar thermal, wind, ocean thermal gradients, and photovoltaic systems used to produce electric power could be used in decentralized or centralized applications depending on economies of scale. The potential exists for providing a large proportion of the electric power needs for the Nation from solar conversion stations without storage systems. However, the realization of the economical storage systems will substantially increase overall applications of solar energy.

Bioconversion is possible today,but it is not economically attractive. Converting wastes to fuels needs to be demonstrated on a large scale, and the use of biota as fuel is in the early study stages.

Program Plan:

The objective is to develop proof-of-concept experiments that will allow program management to concentrate at an early date on those technologies which show the most promise toward providing the Nation's energy requirements. It should be possible at the end of the five-year program to predict the complete range of the beneficial effects and the extent of application and utilization of solar energy.

Solar heating and cooling of buildings is entering the pilot plant stage. Applicability studies, design criteria development, and component testing will be conducted on a much enlarged scale. Operating pilot systems will be installed in single-family and multifamily dwellings, in agricultural buildings, and in commercial/industrial buildings. This development could provide the basis for an industry prepared to manufacture solar energy heating and cooling systems in large quantities.

Major emphasis in the solar thermal conversion area will be placed on the research and technology developments of key subsystems for the optical transmission/central receiver tower approach. Three system design efforts will be conducted in parallel. Design, hardware procurement and integration, and a testing program of a 10-MW(e) pilot plant will be achieved.

A series of experimental wind generator systems in increasing size and performance capability will be constructed and tested. The first unit of 100-kW(e) size will be built in the first year. Four additional advanced units will be developed and used in experimental operation in the following years. Multiunit wind generator systems making up a wind "farm" up to 10 MW(e) will be constructed late in the program period.

The ocean thermal energy conversion subprogram emphasis will be placed on the design, production, and testing of system components. Key elements that will require significant adaptation of existing technology include the heat exchanger, the deep-water pipe, and the overall plant structural design. A test facility is planned for construction.

The photovoltaic program will concentrate on the single-crystal silicon approach with only a modest research and development effort on alternative materials and concepts. Materials development and improved processes are necessary to permit automated production of cells to accomplish major cost reductions.

The construction and operation of a small-scale pilot plant involving the conversion of wastes into methane would lead to a 10 ton/day pilot plant later in the period. Laboratory-scale studies of methods for converting various organic materials to electric power, including research on biomass production, would be prominent in the program plant.

Supporting Evidence:

With the primary exception of photovoltaics, the development of practical systems will not require high technology. The research and development costs for solar energy should be very small in relation to the value of energy saved. Because solar energy systems are capital intensive and practical systems have not been fully developed, Federal involvement in the program is warranted.

Life-cycle costs for solar building heating and cooling look attractive, but capital investment is high and deters market formation. Component cost and reliability must be improved and has a high probability of success.

Solar thermal systems are currently projected to provide power at approximately double the cost of alternative nonsolar methods. New design concepts are being investigated for cost reduction purposes.

Wind energy systems can be built but must provide evidence of economic viability and aesthetic acceptance. Ocean thermal gradients can be exploited if appropriate thermodynamic cycle machinery can be engineered to operate in a hostile environment. Bioconversion systems are possible today, but many questions about degree of impact and economic viability must be answered by proof-of-concept experiments.

There is no potential impact from solar energy heating and cooling systems on the environment or safety. Problems associated with public and institutional acceptability will require resolution in the near-term.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Heating and Cooling of Buildings ..	12.8	13.6	10.7	6.5	6.4	50.0
Solar Thermal	5.0	7.0	7.5	8.5	7.5	35.5
Wind Energy	6.2	6.7	7.2	7.5	4.1	31.7
Ocean Thermal	1.9	3.5	4.5	7.2	9.5	26.6
Photovoltaic	4.2	5.6	7.0	8.0	11.0	35.8
Bioconversion	2.4	3.5	4.5	4.5	5.5	20.4
TOTAL	32.5	39.9	41.4	42.2	44.0	200.0

C. Geothermal $185M

Program Goal:

To exploit geothermal sources by developing and demonstrating the technology that would allow commercial production of electrical power and other energy uses in environmentally acceptable ways.

FY 75-79 Program Objectives:

1. To increase present knowledge of the location, nature, and extent of the Nation's geothermal energy resources.
2. To identify and resolve the environmental, legal, and institutional barriers to geothermal resource utilization.
3. To advance, through technology development, the operational efficacy and efficiency of relevant components, devices, and techniques as required to achieve practical geothermal resource utilization.
4. To accelerate, through demonstration plants, the commercial production of electricity from geothermal resources.

Contributions to the Energy System If Success Is Achieved:

The five-year effort will greatly enhance the industrial capability to locate and evaluate geothermal resources, to identify and solve the environmental problems associated with geothermal developments, to clarify institutional and legal issues involved in geothermal energy uilization, and to upgrade the existing technology available for geothermal development and utilization, including power generation and heat applications.

The present program is designed to stimulate the commercial production of at least 20,000 MW(e) by 1985 from various types of geothermal resources (equivalent to an oil consumption rate of approximately 0.7 million barrels of oil per day) plus important additional fuel savings through use of geothermal energy for such nonelectric purposes as space heating and air conditioning, extracting minerals, and desalinating brines. The corresponding goals for the years 2000 and 2020 are 80,000 MW(e) and 200,000 MW(e), which would save nearly 3 million and 6 million barrels of oil per day, respectively. The equivalent heat values for 1985, 2000, and 2020 are 1.5, 6.0, and 15 x 10^{15} BTU's.

Program Plan:

The five-year program is a coordinated effort toward meeting all objectives for four types of geothermal resources and preparing for prompt demonstration of energy production from two other types.

Each type of resource poses special problems in location and distribution, reservoir analysis, environmental hazards, energy conversion and utilization and in the severity of and solution time of technical questions involved in bringing the resource to on-line production. Each experimental facility will, therefore, be a flexible test bed for research and engineering development as well as for demonstrations of electrical generation and the other uses of geothermal heat. Throughout the program effective technology transfer will be encouraged by cooperative arrangements with industry, and special attention will be given to the institutional, legal, social, and environmental issues bearing on utilization of that particular type of resource.

Under this program plan, demonstration plants using four of the six advanced resource types will be completed and operated jointly with industry to obtain engineering and economic data. Two other resource types would be demonstrated soon after.

Resource Type	Demonstration
1. High-temperature (> 180°C) convective	
a. Low-salinity (20,000 ppm or less)	1978
b. High-salinity (over 100,000 ppm)	1979
2. Low-temperature (<180°C) convective	1979
3. Geopressured sedimentary basins	1979
4. Hot dry rock	1981
5. "Normal" geothermal gradients	1983

Supporting Evidence:

One geothermal resource type is presently being used to produce power in the U. S. – dry steam generating 400 MW(e) at The Geysers near Santa Rosa, California. Six other types – brines at high temperature and low salinity, high temperature and high salinity, low temperature and low salinity, and in geopressured reservoirs, plus dry hot rock at shallow depth and in deep, normal-gradient formations – are potentially available for economic energy recovery. The first of these is being utilized in several foreign installations.

Major technical problems to be solved are concerned with the handling of corrosion and toxic substances and the successful utilization of low-temperature fluids. Practical binary cycles that use low-temperature working fluids must also be developed.

Theory and engineering design are available to support further development in the use of several resource types, and experimentation and demonstration have begun for a few. What is required now is an effort to attempt successful demonstration of the concepts.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Resource Assessment and Exploration	9.7	10.5	10.0	10.0	9.0	49.2
Environmental, Legal, and Institutional Research	3.4	3.5	2.5	1.0	.5	10.9
Resource Utilization	16.9	17.5	18.3	14.9	11.0	78.6
Advanced Research And Technology	10.0	9.5	10.0	9.8	7.0	46.3
TOTAL	40.0	41.0	40.8	35.7	27.5	185.0

TASK 6–SUPPORTING PROGRAMS

A. ENVIRONMENTAL EFFECTS $650M

Program Goal:

To establish the capability to determine and control effectively the environmental and health insults from the energy system through development of a sound technical and scientific basis for ensuring protection of the total ecosystem.

Program Objectives:

1. To determine the nature of pollutants and the quantity in which they are produced and to devise means of identifying and measuring the pollutants.
2. To determine the means by which pollutants are injected into the environment, the means by which they are diffused, and the distribution of pollutants at their final point to rest.
3. To determine the health, welfare, social, and ecological effects of pollutants on man and on all aspects of his environment.
4. To develop standards and specifications that will lead to effective protection of the environment.

Contribution to the Energy System If Success Is Achieved:

Implementation of the environmental research program described will make a vital contribution to the national energy system in three critical areas: (1) cost, (2) usability of domestic energy sources, and (3) timeliness in implementing energy system initiatives.

With respect to costs, at least $90 billion will be spent by the energy industries in the period 1971-1980 alone to meet established environmental requirements for the limits set on air and water pollutants. This amount of pollution control expenditure will add about 15% to the wholesale delivered national cost of energy over the same time period. By providing the technical and scientific environmental knowledge to be gained from this research and development program, it will be possible to develop and demonstrate environmental controls in conjunction with developing energy technology rather than having to rely on the costly retrofit programs exemplified by the current SO_x control program. It is estimated that the environmental cost to achieve the broad environmental objectives could in this manner be reduced to less than 10% of the wholesale delivered national cost of fuel.

The technological development and implementation of coal-based energy systems for near-term energy self-sufficiency must be sensitive to the effects that residuals from the system will have on health, welfare, and the ecological system. If this sensitivity is incorporated into the development and implementation process, these domestic resources can be broadly utilized in harmony with the environment. These effects act as a constraint on the technical requirements for control, the siting of the system, and the value of the system as a producer of energy. Further, knowledge of the effects of the system before it is implemented will avoid the enormous costs associated with the need to retrofit controls on an operational system or to cleanup the wastes once they have been discarded. The environmental research program will provide the technical basis for understanding these environmental consequences and for balancing the environmental and energy system costs to the society in an equitable manner.

While in theory the environmental research program does not add 1 BTU to the energy balance, in practice achievement of the energy supply forecasts made by each technology panel are dependent on demonstrating to a concerned and increasingly sophisticated public that environment impacts are understood and controllable to an acceptable level. Recent history has demonstrated the delays that can occur owing to the lack of a sound understanding of energy-related environmental questions. Examples of these delays which have affected energy supplies have been the Alaska pipeline and delays in nuclear licensing. Delays also affected implementation of environment controls, as exemplified by litigations of utilities against installation and operation of SO_X flue-gas cleaning technology. The environmental research program would provide the basic understanding necessary to evaluate and measure environmental impacts, determine their effects, and develop and implement timely and minimum cost environmental controls.

Successful implementation of this environmental research program will affect all aspects of the energy program and could be the definitive determinant of optimal energy source use and of the feasibility of specific technology approaches. Disruption of the energy program can be prevented by anticipating potential problems related to each technology and by determining as rapidly as possible the effects on health, ecosystems, and society. Perhaps the largest barrier to be faced is the need to convince energy-related technologists and planners that this seemingly distractive commitment must be made at the outset to prevent very major disruptions in energy production.

Program Plan:

1. Pollutant Characterization, Measurement and Monitoring

The research programs in the FY 1975-1979 period will:

a. Develop and apply methods to determine the characteristics of pollutants associated with existing and future energy systems and technologies.
b. Improve precision and accuracy of ambient and source measurement methods and procedures for controlling radiological pollutants.

c. Develop continuous ambient and source measurement methods and procedures for pollutants for which no standard has been established (e.g., fine particulates, sulfate, nitrate).
d. Develop quality assurance procedures for environmental monitoring and measuring activities.
e. Develop and demonstrate advanced monitoring techniques, i.e., remote and in situ sensors.
f. Develop and implement data acquisition, retrieval, and assessment procedures permitting maximum Federal, regional, and local application of monitoring information.
g. Develop more precise performance specifications for calibration of instrumentation used to measure pollutant concentrations.

2. **Environmental Transport Processes**

Specific research activities in the FY 1975-1979 will determine:

a. Cooling-system plume behavior.
b. Atmospheric interactions in both dry and wet-scrubbed plumes from fossil energy systems (especially respirable sulfate-particle formation, SO_2 oxidation rate, interaction with urban pollutants, and NO_x behavior).
c. Dispersion of plumes in rough terrain.
d. Low-level dispersion pathways and ultimate fates of radionuclides from nuclear plant releases, especially at low wind speeds and including building wake effects.
e. Thermal and pollutant dispersion pathways and ultimate fates in streams, lakes, and groundwaters.
f. Physical and chemical transformation of pollutants in streams and lakes.
g. Thermal and pollutant diffusion in characteristic coastal waters.
h. Physical and chemical transformation of pollution in coastal waters.
i. Transfer mechanisms of atmospheric sulfur and nitrogen oxides to soils and economic crops.
j. Impact of moisture and heat release on local climate.
k. Model for precipitation scavenging of sulfur.
l. Dry deposition of atmospheric pollutants.

3. **Effects: Health, Ecological, Welfare and Social**

Specific health-effect research activities in the FY 1975-1979 time period are:

a. Strengthening of scientific bases for existing primary ambient air quality standards. Although these standards were formulated upon the best available information at the time of their promulgation, there is a pressing need to place these standards on as firm a scientific basis as possible before they are implemented. Gaps in knowledge are particularly evident with respect to nitrogen oxides.
b. Evaluation of health effects associated with exposures to air

pollutants for which ambient air quality standards do not presently exist. These include effects of fine particulates and suspended sulfates, as well as known or suspected carcinogenic hydrocarbons.

c. Evaluation of health effects associated with exposures to trace metals and persistent chemicals. Although these are in reality multimedia problems, airborne exposures can be important. Current strategies for long-term control of lead mobile source emissions and for control of lead and cadmium stationary source emissions are dependent upon availability of additional health effects information.

d. Evaluation of health consequences resulting from the impact of fuels and fuel additives upon regulated as well as nonregulated pollutants. Work includes safety assessment of catalysts to be used in emission control systems for automobiles as well as protocol development for safety assurance testing.

e. Definition of effects of simultaneous exposure to a number of air pollutants. This includes assessment of nonpulmonary effects due to air pollution, such as decreased resistance to infection, and impact upon health of future generations via teratogenic or mutagenic effects.

f. Investigation of long-term low-level effects of fossil fuel and radioactive pollutants. This will include studies of genetic and late somatic effects and is of particular importance because such effects will ultimately aid in the determination of the safe levels for pollutants in the air, water, land, foods, etc.

g. Development of means of combating adverse effects of pollutants on exposed humans. Such efforts are needed to decrease harmful effects in cases of acute, intermittent, and long-term low-level exposures.

h. Provision of information on health effects essential to cost-benefit-risk decisions in the choice of energy systems when diverse, competing technologies exist.

Specific ecological effects research in the FY 1975-1979 time period will:

a. Assess the environmental effects and impacts of coal, oil, oil-shale, uranium, and geothermal extraction techniques and predict ecosystem effects, permitting enhancement of benefit-cost-risk ratios by suitable land management policy.

b. Determine the environmental effects of radionuclide, hydrocarbon, and other fuel transport, storage, or waste releases during energy conversion and waste disposal. This will include determining the accumulation ratios and transfer rates of secondary pollutant dispersal through the food chains and other pathways and determining strategies for concentration and/or decontamination in order to minimize residual long-term ecosystem effects, including those impinging on man.

c. Determine pollutant pathways and toxicities so as to guide routine and nonroutine releases from energy conversion and reprocessing plants. Both geochemical and ecosystem studies will be conducted to provide guidelines and criteria for siting of process facilities and disposal areas for both liquid and solid wastes generated by both nuclear and nonnuclear plants.

d. Determine the ecosystem costs of thermal shocks from power plant waste-heat release, of entrainment and impingement in the cooling systems, and of cooling tower blow-down as well as the impact of anti-fouling additives. Additionally, the ecosystem impacts and synergistic effects of effluents, such as radioactive materials, trace metals, noxious gases, organic compounds and other substances produced during energy generation, will be evaluated, and management strategies will be instituted for minimizing these impacts.
e. Develop biological indices (species, diversity, fecundity, natality, mortality, etc.) for ecosystem impact evaluation. A systems approach encompassing laboratory, greenhouse, microcosm, and large-scale field experimentation will be used to address the problem. This systems approach requires a model that is structured in such a way that those subsystems most affected by pollution can be sensed. A more detailed analysis of these components will then be made with a view to assessing the site, time, and mechanism of potential pollution effects so as to guide siting to the least environmental damaging places.
f. Conduct large-scale ecosystem studies on dedicated, controlled-access parcels of land and water, such as environmental research parks, and through the biome studies developed under the International Biological Program.
g. Produce a number of relatively simple, reliable estimators of ecological impact and estimate the extent and duration of observed effects using the above capabilities and data base.

Social and welfare effects research in the FY 1975-1979 time period will address:

a. The assessment of material deterioration problems in the field at present.
b. The factors affecting erosion of stone—characterization and parametric evaluation.
c. The study of pigment degradation in artistic and other works.
d. The assessment of construction metals and their uses in construction, art, and transportation.
e. Development of a reasonable standard protocol for societal assessment techniques to be used by different energy research and development groups (opinion surveys, handbooks, etc.).
f. Development of and testing of models of value changes in impact assessments. Compare results of system analyses used by all groups.
g. Implementation and dissemination of results (in lay terms) to Government policy-making bodies, etc.

4. Environmental Assessment and Policy Formulation

Priority research in the FY 1975-1979 time period will:

a. Determine the ability of existing and proposed institutional structures for energy decision making to accurately represent the environmental concerns of all segments of the population.
b. Develop methodologies for intercomparing the environmental risks and benefits of highly disparate energy systems.
c. Lead to improved quantification of both environmental costs and benefits to society and development of techniques by which the cost of pollution control can be more effectively internalized.
d. Develop methodologies for synthesizing information produced by the environmental research programs.
e. Analyze alternative implementation techniques for reducing environmental impact (e.g., environmental impact statements, environmental standards, economic incentives).

Supporting Evidence:

It is clear that a sound base of scientific capability exists for this work. No major difficulties with scientific feasibility are foreseen in achieving the goals. Few engineering problems are anticipated, but close cooperation between biologists, environmental scientists, and technology development engineers will be required to minimize environmental impacts of present and new technologies. The major potential barriers are: (1) inadequate communication between the environmental scientists and the energy technology developers and (2) lack of established policy for the timely incorporation of environmental impact data into the development and implementation of energy systems and associated technology.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Pollutant Characterization, Measurement and Monitoring ...	13.3	18.5	21.1	21.4	22.0	96.3
Transport of Pollutants	20.5	24.0	23.0	23.0	19.5	110.0
Effects Research	69.1	76.4	78.4	95.0	94.8	413.7
Environmental Assessment and Policy Formulation	3.0	3.0	6.0	8.0	10.0	30.0
TOTAL	105.9	121.9	128.5	147.4	146.3	650.0

B. BASIC RESEARCH $300M

Program Goal:

To explore basic phenomena, processes, and techniques in those physical, chemical, biological, environmental, and social sciences areas bearing on energy and to ensure the development of new basic knowledge in these areas.

Program Objectives:

1. Materials

a. To understand the effects of high-temperature environments and thermal shock on material strength, microstructural changes of surface, and bulk properties. To provide the understanding needed to synthesize new materials suitable for energy applications under these environments.
b. To understand radiation effects, void formation, sputtering, ion-penetration effects of individual ions from nuclear reactions, and embrittlement by hydrogen and radiation.
c. To better understand superconductivity, electronic conduction at high temperatures, insulator breakdown, electrolyte behavior, and ion conductance phenomena relevant to energy production and utilization.
d. To understand the corrosion processes related to energy systems, including stress and sulfur corrosion, grain boundary penetration, and liquid-metal compatibility.
e. To understand photovoltaic properties, effects of impurities, and new semiconductors.
f. To understand the properties of ceramic materials including strength and resilience.

2. Chemical, Physical, Engineering Sciences

a. To enlarge our understanding of hydrogen production by thermochemical, photochemical, and biochemical processes from nonfossil sources including water. To expand our understanding of hydrogen storage systems, principally as hydrides.
b. To understand catalysis and how surfaces catalytically alter reaction mechanisms sufficiently to be able to design and identify new catalysts and catalytic techniques, to identify and understand the role of reactive intermediates, to understand the structure of enzymes and how they effect catalytic alteration of reactions, including immobilization.
c. To understand kinetic and heat-transfer processes which affect combustion efficiencies and other energy processes.
d. To provide needed thermodynamic data on low-temperature liquids, high-temperature gases, liquid-metal alloys, hydrogen-

producing reactants, and intermediates, and to enlarge understanding of theory of solutions and complex reaction equilibrium.

e. To understand turbulent mixing in the atmosphere and ocean, in polymer solutions, and in two-and-three-phase flow. To be able to effect more efficient reactions by understanding and applying the principles of turbulent mixing fronts and flows in porous media.
f. To understand the chemical and physical interactions involved in separation processes. To understand laser stimulated interactions as applicable in isotope separation.
g. To provide needed nuclear properties for new fuels and other nuclear materials. To better understand interactions in molecular, atomic, and nuclear physics, including low- and high-energy interactions.
h. To improve understanding of electrochemical processes including oxygen reduction mechanisms in aqueous solutions, ion mobilities in solid electrolytes, electrode potentials, overpotential foaming, and current density limits.
i. To be able to measure pollutants and/or trace elements in the ppm and ppb ranges, measure transport and thermodynamic properties, and to measure particle-size distributions in submicron range.

3. Biological

a. To understand the bioconversion of animal and plant wastes to usable fuels including the photosynthetic process and the fixation of nitrogen.
b. To understand detoxification of energy-related wastes and the biological effects of toxic substances.
c. To understand the aspects of hydrology, oceanography, climatology, and meteorology which are most affected by energy systems, including dynamics affecting transport and disposal of thermal and material loads at local, regional, and global levels.
d. To understand the ecosystem, particularly the interactions resulting from energy production and utilization.
e. To enlarge understanding of geochemistry and environmental geology, including faulting, rupture, slope stability, seismology, and rock and soil mechanics.

4. Plasmas

a. To understand the behavior of plasmas, the factors that affect their interactions with electromagnetic fields and radiation, and direct energy conversion systems.
b. To encourage thinking about very large energy supplies such as orbital solar stations, colliding-beam fusion reactions, kinetic energy of ocean currents, rotational energy of spin and orbital motion of the earth, and nuclear energy storage concepts.

5. **Mathematical and Social**

a. To develop mathematical and computer techniques for handling large and complex technical and socioeconomic energy models. To further develop mathematical approaches to energy problems.
b. To understand social and psychological responses, including motivational studies and national attitude analyses, as related to changing energy situations. To better understand the energy needs for population support.
c. To develop techniques needed to understand the effects of national regulatory policy and international relations on the dynamics of energy research and development.

Contributions to the Energy System If Success Is Achieved:

The overall benefits of research are to ensure development of efficient energy concepts, including the identification of new means for meeting energy requirements, and to provide the base of knowledge that will facilitate solutions to currently unanticipated problems, thus reducing national costs of energy utilization. The recommended research is aimed mainly towards obtaining knowledge that will ultimately lead to greater social and economic benefits from energy utilization and that will lead to a lessened impact on our energy resource base and on our environmental and ecological systems.

Specifically, research on materials should narrow the gaps in the fundamental understanding needed to improve, control, and predict the properties of materials utilized in the exceptionally hostile environments of energy processes. Superconducting materials research is expected to make very long distance transmission of electricity possible, providing savings in transportation costs and flexibility in siting of power plants. Research in chemical, physical, and engineering science areas should lead to more efficient and environmentally acceptable utilization of our resources. Such research could lead, for example, to economical production of hydrogen from water or renewable nonfossil sources. Advances in catalysis, a field ripe for exploitation, could significantly affect the economics of such conversion processes as coal liquefaction and gasification. Basic biological research will increase our knowledge of biochemical generation of fuels from organic materials and the biological and environmental effects of toxic effluents. Plasma research supports conversion techniques, such as MHD, fusion, gas lasers and thermionic devices. Contributions from discoveries of entirely new concepts could be revolutionary in nature and could alter the entire approach to energy production and utilization. Basic work in the mathematical and social sciences leads to improvements in many fields, especially in the socioeconomic area where better understanding could result in a more stable and responsive technical, socioeconomic, and political system.

Program Plan:

Part of the multidirectional research program is designed to find answers to questions now visible. Another part is intended as insurance against unknown future barriers to development progress. A very small part of the multidirectional research effort is to encourage creativity and imagination along lines not yet chartable in the long-term concerns for renewable energy.

The greatest value is realized from research when fruition precedes the demand for implementation. For example, research on fusion reactor materials problems is not expected to impact in the same time frame as research on catalysis for coal conversion processes. However, because of the lead time required to provide the understanding to resolve the materials problems of the fusion reactor, it is imperative that materials and catalysis research be accelerated as soon as possible. Every effort is expected to plan the research so as to anticipate the needs of future energy developments while at the same time providing the fundamental support needed for currently developing programs. The most promising proposals for research that address the specific objectives cited above will be supported as necessary to expand basic understanding.

Since research frequently suggests quite new lines of development, not contemplated when the program was first defined, flexibility must be assured to most effectively capitalize on new advances.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Materials	8	11	12	12	12	55
Chemical, Physical, Engineering	16	22	24	24	24	110
Biological	12	15	17	18	18	80
Plasmas	3	4	5	4	4	20
Mathematical	4	6	8	9	8	35
TOTAL	43	58	66	67	66	300

C. MANPOWER DEVELOPMENT $50M

Program Goal:

To support the energy research and development program by ensuring that technical and managerial manpower skills are available in quantity and quality sufficient to meet the needs of the program.

FY 75-79 Program Objectives:

1. To enlarge educational faculty capabilities to educate and train technical manpower in the skills required to conduct energy research and development.
2. To enhance the effectiveness of managerial personnel in Government and industry in planning and executing programs in energy research and development.
3. To enlarge the base of manpower skilled in energy and energy-related research and development by supporting student participation in energy and energy-related studies and training activities.
4. To enlarge manpower training capabilities in energy research and development organizations to retrain and redirect technical manpower at all levels.

Contributions to the Energy System If Success Is Achieved:

A five-year $10 billion Federal program in energy research and development represents at least 50% increase over previous projections. Manpower requirements will be increased similarly. At an average rate of $2 billion per year and an average cost per technical man-year of $50,000, the energy research and development program would employ 40,000 scientists, engineers, and technicians. Currently, only half that number are employed in federally supported energy research and development. While the potential for redistribution of technical manpower is high, reorientation or retraining is still necessary to a significant degree, and major growth in the longer term must come from the students now in universities.

The proposed funding level for manpower development would support a program that would reach over 2000 people annually, many of them faculty and managers responsible for education and training of the future manpower pool.

In recent years, Government support for such a program has diminished; this is reflected in a lack of Government direction in the development of manpower to meet national needs.

Program Plan:

To lay the proper foundation for a program of education and training directed to the development of a manpower base for energy research and development, initial emphasis must be on reorienting the faculty and managers responsible for such training. FY 75 funding would be used primarily for conducting or supporting institutes, special courses, workshops, conference, and off-campus appointments for university faculty currently teaching courses in science or technology or conducting research in science and engineering fields.

Program funding will support students or postgraduates who are pursuing studies in science and engineering. Traineeships, scholarships, research stipends, and post-doctoral fellowships would be granted that would permit them to pursue studies and research in energy and energy-related subjects.

Finally, a moderate program of special courses, workshops, and conferences for managers would orient managers to the particular problems they will face in augmenting the technical manpower forces under their control.

Once a foundation has been laid by establishing a base of educators that would produce the needed manpower, emphasis can be shifted to the student or trainee, and more direct benefits should be forthcoming.

A cooperative program with national laboratories and contractors would lead to the retraining and reorientation of technical workers whose skills were inappropriate to specific needs. Government funding would support external educational assistance, manpower increases needed to conduct training programs, and stipends necessary to support trainees while undergoing training.

Supporting Evidence:

Research and student education conducted in U.S. universities is largely dependent on the source of support funds received and the stipulations attached to those funds. Programs offered and course structures are also dictated by the perceived need for graduates in particular disciplines. The need for a greatly enlarged effort in energy research and development has not been widely perceived, and Government funding for energy research and development has been somewhat stable. What is even more significant is the relatively new perception that coal would play a major role in energy supply for the remainder of this century.

It can be expected that this need for scientists and engineers capable of working on all aspects of the energy problem will be reflected in future support to U.S. universities, but a lead time is inherent to this shift in emphasis. Therefore, it is imperative that the Federal Government initiate such a program to reduce that lead time to the minimum practical.

Budget:

	Dollars in Millions					
	1975	1976	1977	1978	1979	Total
Faculty Orientation	1.5	2.4	3.0	3.0	3.0	12.9
Managerial Training and Orientation	0.5	0.6	0.5	0.5	0.4	2.5
Student & Postgraduate Support	1.5	2.5	4.5	5.0	5.5	19.0
Industry/Laboratory Manpower Dev. Program	1.5	3.5	4.5	3.8	2.3	15.6
TOTAL	5.0	9.0	12.5	12.3	11.2	50.0

Appendix B

MAJOR RESEARCH AND DEVELOPMENT STRATEGY OPTIONS

Ten strategy options are available to policy makers whose goals are self-sufficiency, environmental improvement, and low energy cost. These are listed in Table B-1.

The first option (Class I) seeks balanced attainment of all three goals. Emphasis on the environmental goal (Class II) requires that the major effort go to obtaining and maintaining a clean environment. The options differ within that priority according to whether the secondary emphasis is placed on security, prosperity, or a balanced effort to achieve both. Classes III and IV place first priority on attaining security and prosperity, respectively, with

Table B-1.—POSSIBLE RESEARCH AND DEVELOPMENT STRATEGIES (RELATIVE PRIORITIES AMONG GOALS)

I.	Balanced Attainment of All Three Goals	
II.	A.	Environment—Security—Prosperity
	B.	Environment—Prosperity—Security
	C.	Environment—Balanced Security/Prosperity
III.	A.	Security—Prosperity—Environment
	B.	Security—Environment—Prosperity
	C.	Security—Balanced Environment/Prosperity
IV.	A.	Prosperity—Security—Environment
	B.	Prosperity—Environment—Security
	C.	Prosperity—Balanced Environment/Security

corresponding follow-up choices among the remaining goals. Implications of the four major strategies are discussed in the following sections.

Analysis of Research and Development Strategy Options

Class I. Balanced Attainment of Environment/Security/Prosperity. This approach holds that the Nation is in reasonably good shape as regards each goal and that there are no clear preferences for priorities among the three. A research and development program would be structured to make gradual progress toward each goal. This progress would be uneven, to be sure, as different technologies became economically viable at different rates, but the overall trend would be one of steady improvement in all three areas. If a big breakthrough occurred in one area, research and development funds would be shifted out of that area into the other two. If one area failed to show reasonable progress, it would draw research and development money from the other two until it began to show more movement. The "something-for everybody" character of this option makes it attractive. The difficulty is that it postpones attainment of any one goal until all of them can be attained.

Class II. Environment First. The Class II options proceed from a judgment that economic prosperity and security are adequate for the moment and that a clean environment should be the first priority. Research and development would focus on identifying and removing undesired environmental effects of energy technologies. Ways to use resources cleanly even at higher prices for energy would be a major research and development effort. Environmental quality would be the determining factor when considering the introduction of new processes or the advisability of increasing imports.

Among options IIA, IIB, and IIC, proponents would differ with respect to what should be done once satisfactory progress had been made toward a clean environment. Some would seek security or self-sufficiency next; others would concentrate on lowering costs; and still others would pursue both on a balanced basis, thereby postponing the time of attainment of both.

Class III. Security First. This approach holds that the Nation is too vulnerable to the interruption of crucial energy supplies and that its first task is to regain energy self-sufficiency. The energy research and development program would focus on finding domestic substitutes for imports. As set out in Chapter 5, option IIB is the recommended strategy.

The options within this class differ with respect to the priority between the follow-on objectives, with corresponding implications for the establishment of a specific research and development program.

Class IV. Prosperity First. This set of options completes the list of choices. It would place the major research and development emphasis on achieving low energy costs. Individual options in the class again differ with respect to the priority assigned the two follow-on objectives, clean environment and security.

CRITERIA FOR FUNDING FEDERAL PROGRAMS

The criteria discussed below are listed and rated in Table B-2. In every case, an individual subprogram can be rated "high," "medium," or "low" for each criterion. The differences among these ratings provide guidance for relative funding priorities.

Research and Development Phase

Adequacy of Scientific Base. This is the state of chemical, physical, geologic, and other knowledge about the physical properties and location of various fuel sources. Identification of areas of limited knowledge may suggest important possibilities for developing from basic research the means to increase supply or enhance the efficiency of energy production and use. Prospects for advances depend upon the availability of researchers and the active interest of university centers and industry.

Probability of Future Technological Success. Basic research must be translated into proof-of-concept experiments and pilot and demonstration plants, or their equivalent in other programs. This process sometimes exposes gaps in basic knowledge; lack of component hardware may cause substantial delays. Reasonable assessment of technological feasibility must examine such potential difficulties in an attempt to estimate the "elasticity" of the research and development results to investment–how much positive effect greater funding would have in terms of earlier success or higher probability of success.

Feasible Absorbable Investment. This means the amount of money that can be profitably expended on the project's prospective rate of return. While it is always possible to spend more money, the law of diminishing returns inevitably applies.

Public and Government Consensus That Project Is Acceptable. Primarily from the point of view of environmental integrity, but also from the points of view of health, safety, and security, any new program or increased funding for a program must be measured against public acceptability in the research and development phase and in later stages of production. Although these considerations may be important only in later phases, they should be recognized early in the planning and research and development stage.

Implementation and Production Phase

Production Capability. Can the technology be implemented by the private sector at a profit? This depends on the price of the product relative to its cost. Significant new programs may require massive capital investment by industry and/or Government. Numerous supporting industries will be required for construction, operation, and maintenance of such plants. Availability of capital and of labor must be evaluated on a regional basis with efforts made to minimize possible labor shortages and other dislocations. The ongoing production costs as well as the research and development investment must be estimated to establish the economically viable sale price of the product. To the extent that particular fuels can substitute for each other, their relative costs will influence project viability. The specific constraints are listed individually in Table B-2.

Environmental. Emission-control standards have greatly influenced the choice of fuels for power plants and vehicles. Such standards result from policy decisions based on data regarding hazards. Assessment of hazards should be included in program proposals to ensure balanced decisions. Environmental ill effects must be attributed a meaningful and substantial "cost" in that assessment. Clearly, fuel sources that disrupt the environment relatively less in the stages from mining to burning or disposal, or whose health hazards are relatively less, should be favored. Secondary and higher order undersirable effects, such as the problem of the water supplies required for coal and shale conversion plants, must be anticipated and cost-accounted as well.

Payoff Phase

Timing of Payoff. One of the goals of the energy program is to increase supplies as soon as possible. Accordingly, an assessment of the ability of the research and development program to achieve economic production capability earlier as a result of greater funding is important in determining the level and timing of funding. Estimates of the period of economic use of exhaustible fuel sources should include not only the estimated beginning of useful production but also forecasts of their lifetimes.

Economics of Payoff. If the probability of a program's success, the expected time of payoff, and the costs of creating the product are known, estimates can be made of the product's price and of the demand for it at varied prices. If the price of a new energy-generating system will be higher than the anticipated market price for substitutable products, it will not be economically viable.

Other Considerations

Security. It may be necessary to subsidize production from otherwise uneconomic sources to minimize dependence on foreign oil sources. For example, coal liquefaction and shale retorting may require special support in the form of subsidies or price guarantees to ensure their contribution to total supply as replacements for imported oil.

Political. Deviations from decisions based solely on economic considerations may be required. Decision makers may wish to maintain employment in various parts of the country so that capital investment is distributed throughout the country and among industries or to protect population centers and wilderness areas from unseemly exploration and mining.

Regional Aspects. Certain energy research and development programs may have limited payoff on a national basis, but sufficient local or regional payoff to be justified. Solar energy for space heating in the South and Southwest and geothermal sources in the West appear promising even though total energy production in BTU's is relatively small compared to national needs.

Environmental. Many environmental constraints can be included in the costs of energy production. Some environmental effects, however, are not readily corrected by investments of dollars and effort. These are considered under this category.

Determination of Relative Priorities—An Illustration

The considerations used to set priorities among candidate energy research and development programs are displayed in Table B-2. Ratings based on evaluations contained in the subpanel report in this area compared to subpanel reports regarding other programs have been assigned. The matrix shown is a systematic way to record estimates and arrange them in a manner that facilitates comparisons. The comparisons are the basis for ranking the programs. The energy research and development programs are ranked illustratively on the basis of the criteria indicated. Each program has been assigned a numerical value for each criterion: 3, 2, or 1, on the basis of high, medium, or low desirability, respectively. The reader may choose to substitute other criteria and weights. For example, projects judged to have the highest potential for Savings or Enhancement in Petroleum have been given a 3. Projects offering lower but still substantial potential savings have been given a 2, and those with the lowest potential are assigned a 1 in that column. Those with near-term timing receive a 3, mid-term a 2, and long-term a 1. Illustrative program rankings (totals) are given at the right.

The unweighted total score gives equal importance to each of the criteria. Since certain criteria are more important than others, another criteria weighting scheme was devised. The single criterion deemed most important in each of the three phases (I. Research and Development, II. Implementation and Production, and III. Payoff) was given a weight of 3, the criterion deemed second most important was given a weight of 2, and all other criteria were weighted 1. Other weights could be substituted. In this case, a value of 3 in a criterion weighted 3 generates a contribution of 9 to the total score, a value of 2 in a criterion weighted 1 generates a total score contribution of 2, etc. The total weighted rating for each program summed over all criteria is also shown in Table B-2.

Other schemes could be applied in a similar manner. For example, another approach would be based on multiplicative rather than additive weights, totaling the indicators in each of the three successive phases. This method would tend to favor more strongly those programs having good prospects in each phase, at the expense of those having the same additive but less even prospects. The particular scheme used does not seem to make too much difference. Projects having more-immediate payoffs are generally ranked higher than longer term payoff projects, no matter what scheme is used.

Table B-2.—CRITERIA FOR FEDERAL PROGRAM PRIORITIES

(Weights 3 High, 2 Medium, 1 Low Spending Priority)

I R&D Phase — II Implementation and Production Phase

PROGRAM AREA \ CRITERIA	Adequacy of Scientific Base	Probability of Future Technological Success	Feasible Absorbable Investment	Project is Acceptable	Public and Govt Consensus That Project is Acceptable	Expected Price/Cost of Production	Cost of Substitutes	Environmental Acceptability	Need for Government Role	Adequacy of Resource Reserves	Labor Available
Weighting		3X			2X	3X	2X				
Resource Assessment	3	3	1		3	3	3	3	2	3	3
Mining Coal and Shale	3	3	2		2	3	3	1	2	3	2
Surface Mining	3	3	2		2	3	3	1	3	3	2
Underground Mining	3	3	2		2	3	3	2	2	3	2
Oil Shale Mining and Reclamation	2	3	2		2	2	3	1	2	3	2
Energy and Fuel Transportation Distribution, and Storage	1	3	1		3	2	2	2	1	3	3
Coal and Shale Processing and Combustion	3	3	3		3	2	3	3	3	3	3
Clean Combustion of Coal	3	3	3		3	3	3	3	3	3	3
Coal to Pipeline Gas	3	3	3		3	2	2	3	2	3	3
Coal Liquefaction	2	3	3		2	2	3	2	3	3	3
Support R&D for Coal	3	2	2		3	2	2	3	3	3	2
Pollution Control Technology Coal	3	2	3		3	3	3	3	2	3	2
Conversion Techniques	2	3	3		3	2	2	3	2	3	3
Low BTU Gas	3	3	3		3	2	2	3	2	3	3
High Temp Gas Turbines	2	3	3		3	3	2	3	2	3	3
Magnetohydrodynamics	1	2	2		3	2	2	3	3	3	3
Other (Fuel Cells, Use of Waste Heat)	2	2	1		3	2	3	3	2	2	3
Oil and Gas	3	3	2		3	3	3	2	1	2	3
Geothermal	1	2	2		3	2	1	2	2	2	3
Solar	1	2	1		3	1	1	3	3	3	3
Building Heating and Cooling	3	3	1		3	2	2	3	3	3	3
Other (Centralized)	1	2	2		3	1	1	3	3	3	3
Fusion	1	1	2		3	2	1	3	3	3	2
Confinement	1	1	2		3	2	1	3	3	3	2
Laser	1	2	2		3	2	1	3	3	3	2
Fission	3	3	3		3	3	3	2	2	3	2
LMFBR	3	3	3		3	3	3	2	2	3	2
Other	3	3	3		2	3	2	2	2	3	2
Advanced Transportation Systems	2	1	2		3	2	3	3	2	3	3
Automobile and Truck	1	1	2		3	2	3	3	2	3	3
Air	3	1	1		3	1	3	3	2	3	3
Rail and Bus	2	2	2		3	2	3	3	2	3	3
Ship(Nuclear)	3	2	2		3	3	3	2	1	3	2
Conservation (End Use Sector)	3	3	2		3	3	3	3	3	3	3
Environment											
Multidirectional Res											

II Implementation and Production Phase — III Payoff Phase — IV. Noneconomic Consideration

CRITERIA

Hardware Development	Private Capital Available	BTU's Supplied or Conserved	Saving or Enhancement in Petroleum	Timing (Near, Mid, Long)	Project Score (Unweighted)	Project Score (Weighted)	Federal Regulatory	Environmental	Security	Political	Regional Distribution	PROGRAM AREA
			2X	3X								Weighting
3	2	3	3	3	41	68	1					Resource Assessment
2	3	3	3	3	38	64	3					Mining Coal and Shale
1	3	3	3	3								Surface Mining
2	3	3	3	3								Underground Mining
2	3	3	3	3								Oil Shale Mining and Reclamation
2	3	3	2	2	33	54	2					Energy and Fuel Transportation, Distribution, and Storage
2	2	3	3	3	42	67	3					Coal and Shale Processing and Combustion
2	2	3	3	3								Clean Combustion of Coal
2	3	3	3	3								Coal to Pipeline Gas
2	1	3	3	2								Coal Liquefaction
2	1	3	3	3								Support R&D for Coal
1	1	3	3	3								Pollution-Control Technology Coal
1	2	3	2	2	36	57	1					Conversion Techniques
2	2	3	2	2								Low BTU Gas
1	2	3	2	2								High Temp Gas Turbines
1	2	3	2	2								Magnetohydrodynamics
2	2	2	2	1								Other (Fuel Cells, Use of Waste Heat)
3	3	3	3	3	40	67	3					Oil and Gas
2	2	1	1	2	28	45	1					Geothermal
1	1	2	1	1	27	40	1					Solar
1	1	2	2	1								Building Heating and Cooling
1	1	2	1	1								Other (Centralized)
1	1	3	2	1	29	43	2					Fusion
1	1	3	2	1								Confinement
1	1	3	2	1								Laser
2	3	3	2	2	39	63	3					Fission
2	2	3	2	2								LMFBR
2	3	3	2	1								Other
1	2	3	3	2	35	54	2					Advanced Transportation Systems
2	3	3	3	2								Automobile and Truck
2	2	3	3	2								Air
1	1	3	3	2								Rail and Bus
1	1	3	3	2								Ship (Nuclear)
3	2	3	3	3	43	70	3					Conservation (End Use Sector)
												Environment
												Multidirectional Res

Given the array of potential research and development programs, the mix of programs that can be recommended does not vary too much even when strikingly different strategies are adopted. The criteria can be given extremely high or low weights for environmental acceptability, for example, or for price without drastically altering the ranking of programs. On the other hand, the approach of seeking information to quantify these parameters may become more useful as progress is made on several major programs. Then the projections of costs and technological capacity to overcome environmental constraints can be better evaluated and compared among subprograms.

Illustrative Use of the Criteria Matrix

Rating a Single Program. The basis for rating one program area, Energy and Fuel Transportation, Distribution, and Storage, is described below to illustrate the potential use of the criteria matrix. Subprograms in transmission include demonstration high-voltage a-c and d-c electricity transmission projects, both above ground and below ground, and the use of superconducting underground cables. Storage subprograms include development of sodium-lithium batteries, superconducting magnets, and a flywheel facility. Transportation subprograms include work on surface and underwater arctic ships.

Research and Development Phase. Because much proof-of-concept laboratory work will be required in these programs, Adequacy of the Scientific Base was given a rating of 1. Probability of Future Technological Success received a 3, a high rating. Feasible Absorbable Investment, given the laboratory stage of many subprograms, was considered relatively low and assigned a 1. The projects would improve efficiency and might improve the environment (through underground transmission and submarine tankers having lower spill potential), resulting in a high Acceptability rating of 3.

Implementation and Production Phase. The projects in this area fall in the middle range of the Price/Cost of Production rankings, resulting in a rating of 2. These projects received a Cost of Substitutes ranking of 2 because most of the prospective benefits could be achieved by burning more coal. The necessary Government Role received a 1 rating owing to the short-term payoff of the subject projects and the existence of many industry programs in these areas. Resource Reserves to meet the need to transmit electricity continuously are excellent and are rated 3. Adequate Labor and Capital are available for a rating of 3, but some associated Hardware Development is a challenge, resulting in a rating of 2.

Payoff Phase. If the projects are successful they offer the prospect of conserving substantial BTU's of energy (rating of 3). This would be coal conservation rather than a saving in Petroleum, so the latter is rated 2 as is the Timing criterion.

On the basis of the program rankings, the energy research and development programs have been ordered in priority in Table B-3. The ordering does differ, but not substantially so, between the weighted and unweighted methods. In general, those programs which emerge with highest priorities are those with nearest term potential payoffs.

Table B-3.—ILLUSTRATIVE PROGRAM PRIORITIES BASED ON CRITERIA

Weight Criteria	Total Rank	Unweighted Criteria	Total Rank
Conservation	(70)	Conservation	(43)
Resource Assessment	(68)	Coal and Shale Processing	(42)
Oil and Gas	(67)	Resource Assessment	(41)
Coal and Shale Processing	(67)	Oil and Gas	(40)
Mining Coal and Shale	(64)	Fission	(39)
Fission	(63)	Mining Coal and Shale	(38)
Conversion Techniques	(57)	Conversion Techniques	(36)
Advanced Transportation Systems	(54)	Advanced Transportation Systems	(35)
Energy and Fuel Transportation Distribution and Storage	(54)	Energy and Fuel Transportation Distribution and Storage	(33)
Geothermal	(45)	Fusion	(29)
Fusion	(43)	Geothermal	(28)
Solar	(40)	Solar	(27)

Rating Two Competing Programs. The basis for assigning weights to two closely related programs is described below to illustrate the rationale by which different weights were given to competing programs. Both programs, enhanced oil and gas production and coal liquefaction, have the same goal—production of refinery feed stock.

Research and Development Phase. Adequacy of the Scientific Base is considered excellent in oil recovery, but poor for the development of economically viable coal liquefaction. Both programs are considered to offer high probabilities of Future Technological Success. More work must be done in coal prior to demonstrating economic feasibility, and a larger list of priority projects exists, implying greater Feasible Absorbable Investment here than in oil and gas. Consensus of Acceptability is good for both projects, but coal liquefaction is less acceptable both on the basis of requiring extensive mining and the use of valuable water resources.

Implementation and Production Phase. Coal liquefaction is expected to have worse Price/Cost prospects than enhanced oil and gas recovery. Both proposals augment the supplies of high Cost Substitutes, namely, oil. Environmental Acceptability of both is less than optimal, with debits in both mining and in the risk of oil spills. Need for a Government Role is far greater in coal liquefaction than in oil, where the time of payoff is much shorter and better technology already exists. Abundant Resource Reserves of coal are known to exist, but the extent of exploitable oil reserves is less certain. Labor is Available in both areas, but Hardware Development is less advanced in coal liquefaction. Private Capital is judged to be readily available to implement enhanced recovery of oil but is much less so for coal liquefaction due to the latter's longer term payoff and less certain economics; also the more fragmented coal industry lacks the financial resources of the oil industry.

Payoff Phase. Both coal liquefaction and enhanced oil recovery offer the prospect of enhancing both the BTU's and Petroleum Savings. Timing is more favorable for oil recovery than coal liquefaction.

Project Priority and Project Funding

Programs given the highest priorities—conservation, oil and gas production, and utilization of coal—have been budgeted more liberally than those programs of lesser priority in terms of size and term of payoff. The dollar amounts proposed for individual programs cannot be ranked in the same fashion as the priority, since the overriding criterion is how much funding can be prudently spent. A relatively massive infusion of Federal funding is proposed in the area of conservation. A very helpful increment of Federal assistance to the huge expenditures of the oil and gas industry is included, anticipating that the bulk of investment in these areas will be derived from private sources.

In the case of coal conversion, a variety of ambitious programs has been proposed for substantial funding in conjunction with a substantial contribution from industry consistent with the anticipated capacity to generate the people, hardware, and initial methodologies to push ahead with major pilot and development stage projects. For programs of long-term and mid-term payoff that lack significant private interest at present, such as the breeder and fusion programs, continued support has been proposed to ensure the energy future without interfering with the concentration of the accelerated spending program on shorter term prospects. In the cases of direct and indirect solar and geothermal applications, very large increases in spending have been recommended; however, the dollar amounts are much smaller than those for programs already involving massive construction costs for demonstration plants.

ALLOCATION OF FEDERAL FUNDS AMONG TIME PERIODS

The allocation of Federal funds among time periods by program elements, shown in Table B-4, provides a breakdown of the program elements given in Table 2-1. The key emphasis used in making these time-period determinations is the earliest projected commercial introduction of a technology derived from the combined Federal—industry development rather than the date of successful completion of the research and development program. There are obvious difficulties in assessing whether certain programs will be introduced in the short-term or mid-term, but the allocation is made through the best estimate available at this time.

Table B-4.—ALLOCATION OF FEDERAL FUNDS AMONG TIME PERIODS BY PROGRAM ELEMENTS

Self-Sufficiency Task	($ Millions) Short-Term Objectives	Mid-Term Objectives	Long-Term Objectives
1. Conserve Energy and Energy Resources			
End-Use Conservation	135	15	
Improved Management	60		
High-Temperature Gas Turbine	210	105	
Advanced Cycles, Fuel Cells, and Other	110	100	
Advanced Auto Propulsion	260	40	
Rail, Bus, Ship, and Air Systems	205		
Energy and Fuel Transportation Distribution, and Storage	180	20	
Subtotal	1,160	280	
2. Increase Domestic Production of Oil and Gas			
Oil and Gas	310		
Resource Assessment	120	30	
Subtotal	430	30	
3. Substitute Coal for Oil and Gas on a Massive Scale			
Mining	285	40	
Direct Combustion	200		
Synthetic Fuels	855	415	
Common Technology	350	30	
Subtotal	1,690	485	
4. Validate the Nuclear Option			
Safety, Enrichment, HTGR, and Other	1,100	145	
Breeder Reactors		2,845	
Subtotal	1,100	2,990	
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible			
Fusion			1,450
Solar	50	50	100
Geothermal	85	100	
Subtotal	135	150	1,550
TOTAL	4,515	3,935	1,550

For each major program element, the subprograms and projects were individually analyzed. Examination of the program objectives, program plan, and contribution to the energy economy following successful research and development leads to the determination of those items which are definitely oriented towards early application or those items which are specifically geared for later introduction. Occasionally, estimated divisions of funding amounts were made when the desired information was not sufficient to make a clear determination.

ESTIMATING INCREMENTAL ENERGY VALUES RESULTING FROM RESEARCH AND DEVELOPMENT

The increments in energy savings and energy production that can be expected in 1980 and 1985 as a result of the research and development program are derived by analysis of the expected degree of implementation provided in the technical panel reports. The analysis was performed utilizing the Reference Energy System developed by Brookhaven National Laboratory. The reason for this type of analysis is that many of the proposed technologies will compete with each other for the same market application. This means that only the most efficient and economical technology will contribute to self-sufficiency. Also, when the combined potential of all technologies exceeds the annual requirements, the excess in one sector (e.g., electricity production) cannot be transferred to another sector (e.g., automobile transportation).

The Reference Energy System depicts a total network flow from supply sources through refining, conversion, and distribution to the final utilizing devices. Economic costs and technical efficiencies are included for each element of the energy system. The systems analysis can show the relative magnitude of impacts based on the assumption of successful research and development and timely implementation of the technology. By utilizing the technical panels' input data, the Reference Energy System provides a consistent framework for evaluating energy resource allocation and consumption patterns.

The energy-supply constraints, technical efficiencies of energy processes, and cost information permit one to examine the interactions within the entire energy system and develop the most likely energy future. By restricting the level of imported fuels and analyzing the types of energy sources which can satisfy a particular end use, the model will permit new, higher cost technologies to compete for the unsatisfied demands until the most-efficient resource allocation is found.

COMPARISON OF AGENCY PROJECTIONS AND RECOMMENDED PROGRAMS

It is impossible to provide any firm estimate of what the FY 1975-1979 level of funding would have been for Federal energy research and development in the absence of the President's June 29, 1973, initiative. No official figures exist. The closest approximation to the programs that might have been conducted are agency five-year planning projections submitted during the FY 1975 budget cycle. An early draft of this report stated these amounts as $6622 million. More-precise definition of energy research and development programs and elimination of duplication resulted in the more-accurate estimate of $5931 million shown in Table B-5.

Table B-5.—FEDERAL ENERGY RESEARCH AND DEVELOPMENT OBLIGATIONS BY INDIVIDUAL PROGRAM ELEMENT, FY 1973-1975

	($ Millions)				
	Annual Budgets			FY 75-79 Programs	
Self-Sufficiency Task	Actual FY 73	Planned FY 74	Recommended FY 75	Recommended	Agency Projections
1. Conserve Energy and Energy Resources	52.8	62.3	166.2	1,440	95
Reduced Consumption	12.1	22.3	29.9	210	15
Increased Efficiency	40.7	40	136.3	1,230	80
2. Increase Domestic Production of Oil and Gas	20	19.5	51.7	460	90
Production	12.8	11.2	31.7	310	50
Resource Assessment	7.2	8.3	20.0	150	40
3. Substitute Coal for Oil and Gas on a Massive Scale	88.8	167.2	405	2,175	842
Mining			45	325	
Direct Combustion			30	200	
Synthetic Fuels			240	1,270	
Common Technology			90	380	
4. Validate the Nuclear Option	395.8	517.3	731.7	4,090	3,672.3
Safety, Enrichment, HTGR, and Other	129.7	151.7	216.2	1,245.7	1,091.5
Breeders	266.1	365.6	515.5	2,844.3	2,580.8
5. Exploit Renewable Energy Sources to the Maximum Extent Feasible	82.8	123	217.5	1,835	1,232
Fusion	74.8	98.7	145.0	1,450	1,132
Solar	4.2	13.2	32.5	200	80
Geothermal	3.8	11.1	40.0	185	20
TOTAL	640.2	889.3	1,572.1	10,000	5,931.3
Supporting Programs (incremental Federal funding to present programs)					
Environmental Effects				105.9	650
Basic Research				43	300
Manpower Development				5	50
				153.9	1,000

These projections assume substantial increases over the funding and pacing levels of current programs and include the initiation of large (and as yet unapproved) new construction projects for test and demonstration purposes in later program stages. Futhermore, the $5931 million is the sum of all agency requests rather than an independent overall coordinated program review. Thus, the total $5931 million almost certainly contains duplicate programs. It does not reflect the relative pacing and funding-level priorities that would only have led to a more-constrained estimate in the context of a balanced overall program review.

Clearly, the recommended program represents more than a doubling of the level of Federal effort devoted to energy research and development. Because of the uncertainty of the agencies' planning projections, Table B-5 also displays the data of Table 2-3 on recent budget levels. These permit a more meaningful comparison that shows the trend of actual spending experience in recent years compared to the current plan for the next five years.

Appendix C

CORNELL WORKSHOP PARTICIPANTS

FOSSIL FUEL OPTION

Workshop Members

William Gouse, Jr. (Chairman)
Director, Office of Research and Development
U.S. Department of the Interior

Glenn Beeman
Vice President, Purchasing
Commonwealth Edison
Chicago, Illinois

Lloyd Elkins
Production Research Director
Amoco Production Company
Tulsa, Oklahoma

Ernst Habicht
Staff Scientist
Environmental Defense Fund
Setauket, New York

Fred A. L. Holloway
Vice President, Science and Technology
Exxon Corporation
New York, New York

John O'Leary
Director of Licensing
U.S. Atomic Energy Commission

Eric H. Reichl
Vice President
Consolidation Coal Company
Library, Pennsylvania

Arthur M. Squires
Chairman, Department of Chemical Engineering
City College of New York

Consultant

Harry Perry
Staff Member
National Economic Research Associates, Inc.

SHORT RANGE NUCLEAR OPTION

Workshop Members

Alvin M. Weinberg (Chairman)
Director, Oak Ridge National Laboratory

John E. Cantlon, Provost
Michigan State University

W. Kenneth Davis
Vice President for Thermal Power
Bechtel Power Corporation
San Francisco, California

J. Lee Everett, President
Philadelphia Electric Company
Philadelphia, Pennsylvania

D. E. Ferguson
Division Director, Chemical Technology
Oak Ridge National Laboratory

Milton Levenson
Director, Nuclear Power
Electric Power Research Institute
Palo Alto, California

H. G. MacPherson
Department of Nuclear Engineering
University of Tennessee

INSTITUTIONAL ARRANGEMENTS

Workshop Members

Thomas O. Paine (Chairman)
Senior Vice President
Technology Planning & Development
General Electric Company
New York, New York

Carl E. Bagge, President
National Coal Association

John Corcoran, President
Consolidation Coal Company
Pittsburgh, Pennsylvania

Shearon Harris
Chairman of the Board
Carolina Power & Light Company
Raleigh, North Carolina

Leif H. Olsen
Senior Vice President and Economist
First National City Bank
New York, New York

M. L. Sharrah
Vice President and General Manager
Research & Energy
Continental Oil Company
Staford, Connecticut

Stephen A. Wakefield
Assistant Secretary for Energy
and Minerals
U.S. Department of the Interior

James E. Watson
Manager–Power
Tennessee Valley Authority

LONG RANGE NUCLEAR OPTION

Workshop Members

Hans Bethe (Chairman)
John Wendell Anderson Professor of Physics
Cornell University

Sol Buchsbaum
Executive Director, Research Communications,
Sciences Division
Bell Labs
Holmdel, New Jersey

Milton Levenson
Director, Nuclear Power
Electric Power Research Institute
Palo Alto, California

Chauncey Starr, President
Electric Power Research Institute
Los Angeles, Calfornia

Walter Zinn (Retired)

TECHNICAL REVIEW PANEL
MEMBERSHIP AND CONSULTANTS

Panel I

RESOURCE ASSESSMENT

Members

Harold L. James, Chairman
U.S. Geological Survey
U.S. Department of the Interior

Robert D. Nininger
U.S. Atomic Energy Commission

Glen Kendall
Environmental Protection Agency

Ernest Loeb
U.S. Department of Commerce

H. F. York
U.S. Bureau of Mines
U.S. Department of the Interior
Pittsburgh, Pennsylvania

Thane H. McCulloh
U.S. Geological Survey
U.S. Department of the Interior
Seattle, Washington

John W. Gableman, Executive Secretary
U.S. Atomic Energy Commission

Consultants

James F. Davis
General Manager, Uranium Exploration
Union Pacific Mining Corporation

D. Verle Harris
Professor of Geology
Pennsylvania State University

Wilbur C. Helt
Director, Engineering
and Statistical Service
National Coal Association

Charles D. Masters
Chief, Office of Energy Resources
U.S. Geological Survey

Alex Mills
U.S. Bureau of Mines
U.S. Department of the Interior

John D. Moody
Senior Vice President
for Exploration and Producing
Mobil Oil Corporation

C. Melvin Swinney
Manager of Energy Resources
Research and Development
Southern California Edison Co.

J. Frederic Weinhold
Energy Policy Project
Ford Foundation

James A. Wilson
Past–President
The American Association
of Petroleum Geologists

Panel II

MINING–COAL AND SHALE

Members

William Schmidt, Chairman
Bureau of Mines
Department of the Interior

James A. Curry
Division of Forestry, Fisheries and Wildlife Development
Tennessee Valley Authority

George Davis
U.S. Geological Survey
U.S. Department of the Interior

Robert MacLauchlan
Plant Sciences Division
Soil Conservation Service
U.S. Department of Agriculture

John McWilliams
Bureau of Mines
U.S. Department of Interior

Carrow T. Prout, Jr.
Plant Sciences Division
Soil Conservation Service
U.S. Department of Agriculture

Ray Thacker
Office of Research & Development
Environmental Protection Agency

Carl W. Conner, Executive Secretary
Division of Construction
U.S. Atomic Energy Commission

Consultants

M. K. Barlow
Bethlehem Mines Corporation
Bethlehem, Pennsylvania

A. L. Barrett
Lemar Company
Cloucester, Virginia

Roger Bay
Forest Service
U.S. Department of Agriculture

E. P. Berg
Bucyrus–Erie Company
South Milwaukee, Wisconsin

Thomas Bethell
United Mine Workers of America

James Boyer
Bituminous Coal Research
Monroeville, Pennsylvania

Joseph R. Brennan
National Coal Association

L. J. Burger
WABCO Group of American Standard
Peoria, Illinois

A. William Calder
Joy Manufacturing Company
Franklin, Pennsylvania

Thomas Crocker
Bureau of Mines
U.S. Department of the Interior
Spokane Mining Research Center
Spokane, Washington

Richard Dick
Bureau of Mines
U.S. Department of the Interior
Twin Cities Mining Research Center
Minneapolis, Minnesota

R. L. Drollinger
Harnischfeger Company
Milwaukee, Wisconsin

Thomas V. Falkie
Mineral Engineering Department
College of Earth and Mineral Science
Pennsylvania State University

John G. Ferries
Geological Survey
U.S. Department of the Interior

Charles T. Ford
Bituminous Coal Research
Monroeville, Pennsylvania

Robert Saltsman
Bituminous Coal Research
Monroeville, Pennsylvania

Donald K. Simpson
American Mining Congress

Milford Skow
Bureau of Mines
U.S. Department of the Interior

John P. Strange
Mine Safety Appliance Company
Pittsburgh, Pennsylvania

Kelly Strebig
Bureau of Mines
U.S. Department of the Interior
Twin Cities Mining Research Center
Minneapolis, Minnesota

Woods C. Talman
U.S. Steel Corporation
Pittsburgh, Pennsylvania

Steven Utter
Bureau of Mines
U.S. Department of the Interior
Denver Mining Research Center

Al Van Besien
Bureau of Mines
U.S. Department of the Interior
Denver Mining Research Center

E. M. Warner
Joy Manufacturing Company
Franklin, Pennsylvania

Gordon Wood
Geological Survey
U.S. Department of the Interior

Leonard A. Wood
Geological Survey
U.S. Department of the Interior

James C. Justice
Bluestone Coal Corporation
Beckley, West Virginia

William Kleysteuber
Bureau of Mines
U.S. Department of the Interior
Pittsburgh Mining and Safety
Research Center

Richard M. Lahn
Sierra Club

E. W. Littlefield
Utah International Inc.
San Francisco, California

Thomas Martin
Bureau of Mines
U.S. Department of the Interior
Spokane Mining Research Center

William McClain
Oak Ridge National Laboratory

Wayne McCurdy
Office of Coal Research
U.S. Department of the Interior

Sylvia Milanese
Mining Enforcement and
Safety Administration

E. A. Moulder
Geological Survey
U.S. Department of the Interior

Chuck Phillips
U.S. Soil Conservation Service
U.S. Department of Agriculture

Donald Pierce
United Mine Workers of America

William Poundstone
Consolidation Coal Company
Pittsburgh, Pennsylvania

William J. Powell
American Mining Congress
Washington, D.C.

John Y. Richards
Joy Manufacturing Co.
Washington, D.C.

Ann Roosevelt
Friends of the Earth

James Garvey
Bituminous Coal Research
Monroeville, Pennsylvania

John Geffken
Office of Coal Research
U.S. Department of the Interior

Harold J. Gluskoter
Illinois State Geological Survey
Urbana, Illinois

B. E. Grant
Peabody Coal Company
St Louis, Missouri

W. A. Haley
Caterpillar Tractor Company
Peoria, Illinois

Warren Hall
Director
Office of Water Resources Research
U.S. Department of the Interior

David S. Harper
Mining Progress, Inc.
Charleston, West Virginia

David S. Harwood
Geological Survey
U.S. Department of the Interior

Robert G. Heers
Kaiser Steel Corporation
Oakland, California

Ronald Hill
Environmental Protection Agency
Cincinati, Ohio

Larry Hobart
American Public Power Association
Washington, D.C.

Thomas E. Howard
Joy Manufacturing Co. (Canada Ltd.)
Cambridge, Calt
Ontario, Canada

Louis Hunter
National Independent Coal
Operators Association
Richlands, Virginia

R. H. Jeffrey
Jeffrey Manufacturing Company
Columbus, Ohio

Harry Johnson
Office of the Assistant Director–Energy
U.S. Department of the Interior

Panel III

FUEL TRANSPORTATION, DISTRIBUTION, AND STORAGE

Members

Joseph H. Seelinger, Chairman
Maritime Administration
U.S. Department of Commerce

Ellis R. Boyd, Jr.
Bureau of Natural Gas
Federal Power Commission

Richard Corey
USBM, Bureau of Coal
U.S. Department of the Interior

John A. Krynitsky
Defense Fuel Supply Center
Cameron Station
Alexandria, Virginia

Thomas J. Padden
Office of Research and Development
Environmental Protection Agency

Joe B. Work, Executive Secretary
Divison of Waste Management
and Transportation
U.S. Atomic Energy Commission

Consultants

Leo Donovan
Booz-Allen Applied Research
Bethesda, Maryland

Frank Fulton
Office of Pipeline Safety
Department of Transportation

Larry Hoffman
Mitre Corporation
McLean, Virginia

Harry A. Klester, Director
Engineering Services
Norfolk and Western Railway
Roanoke, Virginia

Olaf A. Larson, Staff Engineer
Process Research Division
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Frank Salzano
Brookhaven National Laboratory

Robert W. Shaw, Jr.
Booz-Allen Applied Research
Bethesda, Maryland

James A. Sisler
Division of Waste Management
and Transportation
U.S. Atomic Energy Commission

Kenneth Treiber
Material and Equipment R&D Command
Fort Belvoir, Virginia

James K. Walters
Division of Transportation
American Petroleum Institute

Marvin M. Williamson
Division of Applied Technology
U.S. Atomic Energy Commission

Panel IV

ENERGY TRANSPORTATION, DISTRIBUTION & STORAGE

Members

F. F. Parry, Chairman
Office of the Assistant Secretary
Energy and Minerals
U.S. Department of the Interior

J. Neal Thompson
Rural Electrical Administration
U.S. Department of Agriculture

Samuel W. Fordyce
Office of Applications
National Aeronautics & Space Administration

Brian C. Belanger
Division of Applied Technology
U.S. Atomic Energy Commission

Paul A. Petzrick
Headquarters Naval Material Command
Washington, D.C.

R. Kamper
National Bureau of Standards
U.S. Department of Commerce
Boulder, Colorado

T. R. Walker
Tennessee Valley Authority

Donald W. Kuhn, Executive Secretary
U.S. Atomic Energy Commission

Consultants

Robert A. Bell
Consolidated Edison Co.
New York, New York

Ralph Gens
Bonneville Power Authority
Portland, Oregon

Edward F. Hammel
Los Alamos Scientific Laboratory

L. F. Lischer
Commonwealth Edison Co.
Chicago, Illinois

James Workman
U.S. Department of the Interior

Panel V

COAL & SHALE PROCESSING & COMBUSTION

Members

William Crentz, Chairman
U.S. Bureau of Mines
U.S. Department of the Interior

Neal P. Cochran
Office of Coal Research
U.S. Department of the Interior

John Cowles
Division of Applied Technology
U.S. Atomic Energy Commission

Robert Hangebrauck
CSL
National Environmental Research Center
Research Triangle Park, North Carolina

Gerald A. Hollinden
Power Resources Planning
Office of Power
Tennessee Valley Authority

John Manning
National Bureau of Standards
U.S. Department of Commerce

Lewis G. Mayfield
National Science Foundation

Alex Mills
U.S. Bureau of Mines
U.S. Department of the Interior

Rufus W. Shivers, Executive Secretary
Division of Applied Technology
U.S. Atomic Energy Commission

Consultants

John B. Anderson
Research and Development Sales
Combustion Engineering Company
Windsor, Connecticut

L. Berkowitz
ESSO Research and Engineering Company
Government Research Laboratory
Linden, New Jersey

W. E. Bond, Vice President
Atlantic Richfield Company
Los Angeles, California

Arthur L. Conn, Director
Government Contracts
Research and Development Department
American Oil Company
Whiting, Indiana

R. G. Daniel
Atlantic Richfield Company
Los Angeles, California

Martin A. Elliot
Texas Eastern Transmission
Houston, Texas

Brian Harney
U.S. Bureau of Mines
U.S. Department of the Interior

W. B. Harrison, Vice President
Southern Service, Inc.
Birmingham, Alabama

Jack Huebler
Institute of Gas Technology
Chicago, Illinois

T. Kelly Janes
Environmental Protection Agency
Research Triangle Park, North Carolina

Harry Johnson
U.S. Bureau of Mines
U.S. Department of the Interior

Martin Kyle
Argonne National Laboratory
Chicago, Illinois

B. G. McKinney
Tennessee Valley Authority

Jere Nichols
Oak Ridge National Laboratory

John A. Phinney
Consolidation Coal Company
Library, Pennsylvania

Paul Pitts, Vice President
Atlantic Richfield Company
Philadelphia, Pennsylvania

Charles Prien
Denver Research Institute
Denver, Colorado

H. M. Seigel
Synthetic Fuels Research Department
ESSO Research and Engineering Company
Florham Park, New Jersey

Paul W. Spaite
Cincinnati, Ohio

Panel VI

CONVERSION TECHNIQUES

Members

Robert E. English, Chairman
Power Systems Division
Lewis Research Center
National Aeronautics & Space Adm.
Cleveland, Ohio

Winfred M. Crim, Jr.
U.S. Army Engineer Power Group
Fort Belvoir, Virginia

James L. Powell
Office of Coal Research
U.S. Department of the Interior

Samuel Schneider
National Bureau of Standards
U.S. Department of Commerce

John Smith
National Environmental Research Center
CSL
Research Triangle Park, North Carolina

Donald K. Stevens
Division of Physical Research
U.S. Atomic Energy Commission

Patrick A. O'Riordan, Executive Secretary
Space Nuclear Systems Division
U.S. Atomic Energy Commission

Consultants

William H. Day
General Electric Company
Schenectady, New York

Martin U. Gustein
National Aeronautics & Space Adm.
Cleveland, Ohio

George Hill
Electric Power Research Institute
Palo Alto, California

William D. Jackson
Electric Power Research Institute
Palo Alto, California

John C. Orth
Electro Technology Division, MERDC
Fort Belvoir, Virginia

Michael Petrick
Argonne National Laboratory

William H. Podolny
United Aircarft Corp Research Labs
East Hartford, Connecticut

Harvey Schwartz
Lewis Research Center
National Aeronautics & Space Adm.
Cleveland, Ohio

George Seikel
Lewis Research Center
National Aeronautics & Space Adm.
Cleveland, Ohio

Paul W. Sapite
Cincinnati, Ohio

Panel VII

ADVANCED METHODS OF OIL AND GAS PRODUCTION FROM FOSSIL FUELS

Members

Edward H. Fleming, Chairman
Division of Applied Technology
U.S. Atomic Energy Commission

M. Marcy Williamson
Division of Applied Technology
U.S. Atomic Energy Commission

J. Wade Watkins
U.S. Bureau of Mines
U.S. Department of the Interior

Gerald Dinneen
U.S. Bureau of Mines
U.S. Department of the Interior
Laramie Energy Research Center
Laramie, Wyoming

Frank Stead
U.S. Geological Survey
U.S. Department of the Interior
Denver Federal Center
Denver, Colorado

John Bredehoeft
U.S. Geological Survey
U.S. Department of the Interior
Denver Federal Center
Denver, Colorado

John Mulhern
Environmental Protection Agency

Robert Tomihiro, Executive Secretary
Division of Applied Technology
U.S. Atomic Energy Commission

Consultants

Lee Aamodt
University of California
Los Alamos Scientific Laboratory

Charles Bliss
Arthur D. Little, Inc.
Cambridge, Massachusetts

John Dew
CONOCO
Ponca City, Oklahoma

Lloyd Elkins
Research Center
Amoco Production Company
Tulsa, Oklahoma

Gary Higgins
Lawrence Livermore Laboratory

Charles Prien
Chemical Division
Denver Research Institute
Denver, Colorado

Don Shuster
Sandia Laboratories

Panel VIII

GEOTHERMAL

Members

Gerald W. Johnson, Chairman
Division of Applied Technology
U.S. Atomic Energy Commission

Richard Green
National Science Foundation

Donald White
U.S. Geological Survey
U.S. Department of the Interior
Menlo Park, California

William C. Klostermeyer
Division of Planning
Bureau of Reclamation
U.S. Department of Interior

Donald W. Klick (USAF)
1400 Wilson Boulevard
Arlington, Virginia

Joseph E. Machurek, Executive Secretary
Division of Applied Technology
U.S. Atomic Energy Commission

Consultants

William Brigham
Stanford University
Stanford, California

David Butler
Standard Oil Company
San Francisco, California

Hamilton Hess
University of San Francisco
San Francisco, California

George V. Keller
Colorado School of Mines
Golden, Colorado

William Ogle
3801 West 44th Avenue
Anchorage, Alaska

Panel IX

SOLAR AND OTHER ENERGY SOURCES

Members

Alfred J. Eggers, Jr., Chairman
Assistant Director for Research
Application
National Science Foundation

Jim D. Andrews
Energy Programs Coordinator
Naval Weapons Center
China Lake, California

Donald A. Beattie
Advanced Energy Research
and Technology Division
National Science Foundation

Walter Carleton
National Program Staff
Agricultural Research Service
Agricultural Research Center, West
U.S. Department of Agriculture

James Johnson
Air Technology Branch
Environmental Protection Agency

William A. Raney
National Program Staff
Agricultural Research Service
Agricultural Research Center, West
U.S. Department of Agriculture

James Rannels
Division of Applied Technology
U.S. Atomic Energy Commission

Ronald L. Thomas
Solar Systems Section
NASA Lewis Research Center
Cleveland, Ohio

William H. Woodward
Space Power & Prop. Division
Office of Aeronautics & Space Technology
National Aeronautics & Space Administration

Robert Woods, Executive Secretary
Division of Physical Research
U.S. Atomic Energy Commission

Consultants

Harold W. Aarstad
(Howard Research and Development)
The Rouse Company
Columbia, Maryland

Marshall E. Alper
Jet Propulsion Laboratory
Pasadena, California

Landy B. Altman, Jr.
Agricultural Research Service
U.S. Department of Agriculture

William H. Avery
Applied Physics Laboratory
Johns Hopkins Laboratory
Silver Spring, Maryland

Gerald J. Barna
Stationary Power Section
NASA–Lewis Research Center
Cleveland, Ohio

Daniel T. Bernatowitz
Solar Cell Branch
NASA–Lewis Research Center
Cleveland, Ohio

H. Richard Blieden
Division of Advanced Energy
Research and Technology
National Science Foundation

Alan L. Butkow
Office of Budget, Programming,
and Planning Analysis
National Science Foundation

Gerald E. Carlson
Agricultural Research Center
U.S. Department of Agriculture
Beltsville, Maryland

Harry R. Carns
Cotton & Cordage Research Branch
U.S. Department of Agriculture
Beltsville, Maryland

Charles S. Chen
Office of Public Technology Projects
National Science Foundation

William Cherry
Engineering Physics Division
Goddard Space Flight Center
Greenbelt, Maryland

Robert Cohen
Division of Advanced Energy
Research and Technology
National Science Foundation

William Cohen
Liquid Rockets Propulsion
Research and Technology
National Aeronautics & Space
Administration

Ernst M. Cohn
Solar and Chemical Power
National Aeronautics & Space
Administration

Patrick Connelly
Office of Construction Mangement–PC
General Services Administration

John Del Gobbo
Office of Public Technology Projects
National Science Foundation

Louis V. Divone
Division of Advanced Energy
Research and Technology
National Science Foundation

Lawrence Falick
Office of Programs and Resources
National Science Foundation

Howard Feibus
Research and Development Department
Consolidated Edison Co. of New York, Inc
New York, New York

Ray H. Fields
Office of Public
Technology Projects
National Science Foundation

Patrick M. Finnegan
Systems Analysis Section
NASA Lewis Research Center
Cleveland, Ohio

Richard S. Greeley
Mitre Corporation
McLean, Virginia

Lawrence Gsellman
Mitre Corporation
McLean, Virginia

Charles Hauer
Office of Public
Technology Projects
National Science Foundation

Lloyd O. Herwig
Solar Energy Program
Office of Public
Technology Projects
National Science Foundation

Harold Horowitz
Division of Advanced Energy
Research and Technology
National Science Foundation

B. C. Hudson
Deputy Group Leader
Lawrence Livermore Laboratory

James Johnson
Water Research
Programs and Projects
Oak Ridge National Laboratory

George Kaplan
Solar Systems Section
NASA–Lewis Research Center
Cleveland, Ohio

Arthur F. Konopka
Social Systems and Human Resources
National Science Foundation

Abrahim Lavi
Professor of Electrical Engineering
Electrical Engineering Department
Carnegie-Mellon University

Bill Legg
Department of the Navy
Office of the Judge
Advocate General

Daniel G. Lewis
National Power Survey Division
Federal Power Commission

Layman T. Miller
Construction and Valuation
Veterans Administration

Walter Morrow
Linc Laboratory
Massachusetts Institute of Technology

Frederick H. Morse
Department of Mechanical Engineering
College of Engineering
University of Maryland

Warren D. Rayle
Fluid Physics and Chemistry Branch
NASA–Lewis Research Center
Cleveland, Ohio

Bruce Reiss
Office of Intergovernmental
Science and Research Utilization
National Science Foundation

Joseph M. Savino
Solar Systems Section
NASA–Lewis Research Center
Cleveland, Ohio

Wigbert Siekhaus
Division of Energy and Environment
University of California
Lawrence Berkeley Laboratory

F. Smits
Bell Telephone Laboratory
Allentown, Pennsylvania

Tom Sparrow
Office of Systems Integration
and Analysis
National Science Foundation

Dwain F. Spencer
Office of Public Technology
Projects
National Science Foundation

James Stillman
Office of the Chief of Engineers
Office of Plans, Research and Systems
Headquarters, Department of the Army

Robert Stromberg
Division 5712
Sandia Laboratory

John J. Surmeier
Division of Social Systems
and Human Resources
National Science Foundation

Siegfried Thunborg, Jr.
Division 5712
Sandia Laboratory

Ivan Tobias
Grumman Aerospace
Bethpage, New York

John Tosh
U.S. Bureau of Mines
U.S. Department of the Interior

Roscoe F. Ward
Associate Dean of Engineering
University of Massachusetts

John Watson
Mitre Corporation
McLean, Virginia

Howard Wilcox
Santa Barbara, California

Robert Williams
Energy Policy Project
Washington, D.C.

Lee S. Windheim
Sr. Vice President
Leo A. Daly Company
Washington, D.C.

James W. Winfrey
National Petroleum Council
Washington, D.C.

Panel X

FISSION REACTORS

Members

Herbert J. C. Kouts, Chairman
Division of Reactor Safety Research
U.S. Atomic Energy Commission

Alton P. Donnell
Bureau of Power on Energy Matters
Federal Power Commission

Hans L. Hamester
Technology & Impact Review Branch
Office of Radiation Programs
Environmental Protection Agency

Paul G. Shewmon
Division of Materials Research
National Science Foundation

William G. Stroud
Advanced Plans Office–Code 110
NASA Goddard Space Flight Center
Greenbelt, Maryland

Long Sun Tong
Reactor Safety Research
U.S. Atomic Energy Commission

Kenneth A. Trickett
Division of Reactor Research
& Development
U.S. Atomic Energy Commission

Merrill J. Whitman
Division of Reactor Research
& Development
U.S. Atomic Energy Commission

John S. Sieg, Executive Secretary
Division of Reactor Research
& Development
U.S. Atomic Energy Commission

Consultants

Manson Benedict, Institute Professor
Massachusetts Institute of Technology
Cambridge, Massachusetts

Spencer H. Bush
Hearst Mining Building
University of California

William Hinkle
Yankee Atomic Electric Company
Westboro, Massachusetts

Howard J. Larson
President & General Manager
Allied Gulf Nuclear Services
Barnwell, South Carolina

Milton Levenson
Electric Power Research Institute
Palo Alto, California

Peter Murray
Westinghouse Electric Company
Pittsburgh, Pennsylvania

Corwin L. Rickard, Vice President
Gulf General Atomic Company
San Diego, California

Fred L. Robson
United Aircraft Corporation
Research Laboratories
East Hartford, Connecticut

Robert Williams
Energy Policy Project, Ford Foundation
Washington, D.C.

Bertram Wolfe
General Electric Company
Sunnyvale, California

Panel XI

FUSION ENERGY

Members

Robert L. Hirsch, Chairman
Division of Controlled Thermonuclear Research
U.S. Atomic Energy Commission

F. Charles Gilbert
Division of Military Application
U.S Atomic Energy Commission

James E. Leiss
Center for Radiation Research
Radiation Physics
National Bureau of Standards
Department of Commerce

Bruce J. Mann
Evaluation Branch, Radiation Operations
Environmental Protection Agency
National Environmental Research Center
Las Vegas, Nevada

Robert E. Price
Defense Nuclear Agency
Washington, D.C.

George R. Seikel
Plasma Physics Branch
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

William R. Rice, Executive Secretary
Division of Controlled Thermonuclear Research
U.S. Atomic Energy Commission

Consultants

Richard Balzhiser
Electrical Power Research Institute
Palo Alto, California

Everett Beckner
Sandia Laboratories
Sandia Corporation

Keith Boyer
Los Alamos Scientific Laboratory

Keith Brueckner
KMS Fusion Incorporated
Ann Arbor, Michigan

John Emmett
Lawrence Livermore Laboratory
University of California

Alan Haught
United Aircraft Corporation
East Hartford, Connecticut

Moshe Lubin
University of Rochester
College of Engineering and Applied Science
Rochester, New York

Phillip Mallozzi
Battelle Memorial Institute
Columbus, Ohio

Russell Meyerand
United Aircraft Corporation
East Hartford, Conn.

Tihiro Ohkawa
Gulf General Atomic Co.
San Diego, California

Corwin Rickard
Gulf General Atomic Co.
San Diego, California

Anthony E Robson
Naval Research Laboratory
Washington, D.C.

David J. Rose
Massachusetts Institute of Technology
Cambridge, Massachusetts

Ramy Shanny
Naval Research Laboratory
Washington, D.C.

Zalman Shapiro
Westinghouse Electric Corp
Pittsburgh, Pennsylvania

Wolfgang L. Wiese
National Bureau of Standards
Department of Commerce
Washington, D.C.

Jim Williams
Los Alamos Scientific Laboratory

Panel XII

CONSERVATION

Members

John H. Gibbons, Chairman
Director, Office of Energy Conservation
U.S. Department of the Interior

Jerome Rothenberg
Office of the Assistant Secretary
Policy Development and Research
Department of Housing & Urban Development

David Didion
National Bureau of Standards
U.S. Department of Commerce

John W. Markert
Office of Construction Management PCDS
Public Buildings Service
General Services Administration

Simon V. Manson
Energy Applications and Special Studies
Office of Applications
National Aeronautics and Space Administration

Maxine Savitz
Division of Advanced Technology Application
National Science Foundation

Mark Seidel
Implementation Research Division
Environmental Protection Agency

Rudy Black
Advanced Research Projects Agency
Department of Defense

Barry Riordan
Council on Environmental Quality

James King
Office of Construction Management PCDS
Public Buildings Service
General Services Administration

Jocelyn C. Waggoner, Executive Secretary
Office of Planning and Analysis
U.S. Atomic Energy Commission

Consultants

David Berg
Environmental Protection Agency

Monte E. Canfield, Jr.
Energy Policy Project
Washington, D.C.

Dennis J. Carney
Vice President, Research
U.S. Steel Corporation
Pittsburgh, Pennsylvania

James Comly
General Electric
Schenectady, New York

Gerald Decker
Dow Corporation
Midland, Michigan

Ronald Doctor
Rand Corporation
Santa Monica, California

Donald Emhiser
PPG Industries
Glass Research Center
Harmarville, Pennsylvania

Arthur P. Fraas
Oak Ridge National Laboratory

Harold A. Golle
General Foods Corporation
White Plains, New York

Walter A. Hamilton
Vice President, Public Affairs Research
The Conference Board, Inc.
New York, N.Y.

Arjun B. Makhijani
Energy Policy Project
Washington, D.C.

John Myers
The Conference Board, Inc
New York, N.Y.

Stanley Ruby
Office of the Secretary of Defense
Advanced Research Projects Agency
Arlington, Virginia

David Swan
Vice President, Technology
Kennecott Copper Corp.
New York, N.Y.

Eric A. Walker
Vice Pres , Science & Technology
Aluminum Company of America
Pittsburgh, Pennsylvania

Panel XIII

ADVANCED TRANSPORTATION SYSTEMS

Members

Ernest N. Petrick, Chairman
Chief Scientist
U.S. Army Tank Automotive Command
Warren, Michigan

Robert A. Husted/TST-46
Department of Transportation

R. D. Ginter
NASA Headquarters

Phillip Schambra
Council on Environmental Quality

John Brogan
Division of Alternative
Automotive Power Systems
Environmental Protection Agency
Ann Arbor, Michigan

Thaddeus S. Mroz, Program Manager
NASA Lewis Research Center
Power Systems Division
Cleveland, Ohio

L. A. Smith, Executive Secretary
Reactor Research & Development
U.S. Atomic Energy Commission

Consultants

Robert Adams
George Sharp Inc.
Naval Architects
New York, N.Y.

Mel Cheslow, Office of Secretary
U.S. Dept. of Transportation

Francis Critelli
U.S. Maritime Administration
Department of Commerce

Steve Ditmeyer
Dept. of Transportation
Washington, D.C.

Robert Falls, Naval Architect &
Hydrodynaminst
U.S. Maritime Administration
Dept. of Commerce

R. Giblom
George Sharp Inc.
Naval Architects
New York, N.Y.

Graham Hagey
Alternative Systems Analysis Branch
Environmental Protection Agency
Ann Arbor, Michigan

Maurice Hauschildt
Propulsion Division
Naval Ship Engineering Center

Kenneth E. Hodge
Aeronautical Operations Systems
Office of Aeronautics & Space Technology
National Aeronautics and Space
Administration

John Horgan
Advanced Industrial Studies
Pratt & Whitney Corp.
East Hartford, Connecticut

Harry W. Johnson
Study & Analysis Office
OEST-National Aeronautics and Space
Administration

Paul Johnson
Study & Analysis Office
OEST-National Aeronautics and
Space Administration

J. Lloyd Jones
Aerodynamics & Vehicles Systems Division
OEST-National Aeronautics and Space
Administration

Gerald G. Kayten
Study & Analysis Office
National Aeronautics and Space
Administration

Zelvin Levine
Maritime Technology
U.S. Maritime Administration
Department of Commerce

Carl Merz
Marine Marketing & Prop. Systems
Turbo-Power Marine Inc.
Division of United Aircraft
Farmington, Connecticut

John Milton
Safety Technology Division
U.S. Coast Guard Headquarters

Carl Schwenk
Research Division
OEST-National Aeronautics and Space
Administration

Lloyd Shure
Power Systems Division
NASA Lewis Research Center
Cleveland, Ohio

R. W. Sliger
National Maritime Research Center
Galveston, Texas

Harold Smith
Turbo-Power Marine Inc
Division of United Aircraft
Farmington, Connecticut

Don Weidhuner
Power & General Support Equipment Branch
Headquarters U.S. Army Material Command

T. Balfour
Operations & Planning for
Marine & Industrial Gas Turbines
General Electric Corporation
Schenectady, New York

J. D. Collins
Engine Research
Scientific Research Lab Building
Dearborn, Michigan

Willard Fraze
Mitre Corporation
McLean, Virginia

Harold J. Gibson
Ethyl Corporation
Ferndale, Michigan

Arnold Goldberg
The Boeing Company
Seattle, Washington

Charles M. Heinen
Vehicle Emissions Planning
Chrysler Corporation
Detroit, Michigan

S. Kaplan
MARAD Project
General Electric Corporation
Schenectady, N.Y.

Reeves Morrison
United Aircraft Corporation
East Hartford, Connecticut

John Motzer
Manager Marine Transportation
Curtiss Wright Corporation
Woodridge, New Jersey

Richard Mullineaux
General Manager
M.T.M. R&D
Shell Oil Company
Houston, Texas

Phillip S. Myers
Mechanical Engineering Dept.
University of Wisconsin

Roy Quilliam
Army Fuels Laboratory
South West Research Corp

Roger Ringham
Vice President, Engineering
International Harvester Corp.
Chicago, Illinois

Ernest S. Starkman
Vice President
Environmental Activities Staff
General Motors Technical Center
Warren, Michigan

Panel XIV

ENVIRONMENT

Members

Stanley Greenfield, Chairman
Assistant Administrator for R&D
Environmental Protection Agency
Washington, D.C.

James Liverman
Division of Biomedical and
Environmental Research
U.S. Atomic Energy Commission

Jesse Lunin
National Program Staff, SWAS
U.S. Department of Agriculture, ARC West
Beltsville, Maryland

Russell Hickey
Division of Environmental Planning
Tennessee Valley Authority

Lewis Gevantman
Program Analyst for Environmental Coordination
and Other Agency Programs
National Bureau of Standards
Dept. of Commerce

Joseph Maher, Executive Secretary
Division of Operational Safety
U.S. Atomic Energy Commission

Consultants

Stanley I. Auerbach
Environmental Sciences Division
Oak Ridge National Laboratory

Louis S. Clapper
Conservation Division
National Wildlife Federation
Washington, D.C.

E. R. Hendrickson
Chairman of the Board
Environmental Science and Engineering, Inc.
Gainesville, Florida

Lester Machta
Air Resources Laboratory
National Oceanic and Atmospheric
Administration
Silver Spring, Maryland

Mortimer L. Mendelsohn
Biomedical and Environmental
Research Program
Lawrence Livermore Laboratory

John M. Neuhold
Ecology Center
Utah State University

John B. Storer
Scientific Director for Pathology
and Immunology
Biology Division
Oak Ridge National Laboratory

Panel XV

MULTI-DIRECTIONAL RESEARCH

Members

Edward C. Creutz, Chairman
National Science Foundation

Frederick H. Abernathy
National Science Foundation

Richard R. Doell
U.S. Geological Survey
U.S. Department of Interior
Menlo Park, California

Elliot S. Pierce
U.S. Atomic Energy Commission
Washington, D.C.

F. Dee Stevenson, Executive Secretary
U.S. Atomic Energy Commission
Washington, D.C.

Consultants

Leo Brewer
Inorganic Materials Research Laboratory
University of California
Berkeley, California

Ann Carter
Brandeis University
Waltham, Mass.

Frederick de Hoffmann
Salk Institute
La Jolla, California

Gerhart Friedlander
Brookhaven National Laboratory
Uptown, New York

George R. Hill
Electric Power Research Inst.
Palo Alto, California

Howard H. Hines
National Science Foundation

Louis C. Ianniello
Atomic Energy Commission
Washington, D.C.

Sidney Law
Northeast Utilities
Hartford, Conn.

John Mehl
National Science Foundation

Ulrich Merten
Gulf Research and Development Corp.
Pittsburg, Penn.

W. L. Stewart
National Science Foundation

T. B. Taylor
International Research and Technology
Washington, D.C.

James Wei
University of Delaware
Newark, Delaware

Kent Wilson
National Science Foundation

Alex Zucker
Oak Ridge National Laboratory

Panel XVI

SYSTEMS ANALYSIS

Members

Stephen J. Gage, Chairman
Senior Staff Member For Energy Programs
Council on Environmental Quality

Leland Attaway
Office of Research and Development
Environmental Protection Agency

William Wetmore
Office of Systems Integration and Analysis
National Science Foundation

Richard F. Hill
Advisor on Environmental Quality
Federal Power Commission

David Wood
Systems Division
Office of Energy Data and Analysis
U.S. Department of Interior

Larry Ruff
Washington Environmental Research Center
Environmental Protection Agency

Marcel Grunspan, Executive Secretary
Office of Planning and Analysis
U.S. Atomic Energy Commission

Consultants

Cyril L. Comar
Cornell University
Ithaca, New York

Sam H. Schurr
Resources for the Future, Inc.
Washington, D.C.

George C. Szego, President
Inter Technology Corporation
Warrenton, Virginia

J. Frederick Weinhold
Energy Policy Project
Washington, D.C.

PRINCIPAL STAFF MEMBERS

Project Director .... Gorman C. Smith

Assistants .... Patricia A. Boorda
Gilbert S. Omenn
Thomas A. Rehm

Coordinator, Cornell Workshops .... Peter J. Auer

Staff Director, Technical Review Panels .... Richard M. Pastore

Staff .... John A. Blasy, Carl W. Conner, Harold E. Kneeland, Joseph R. Maher, Delma Snouffer, F. Dee Stevenson, Robert Tomihiro, Richard H. Williamson, Robert M. Woods, Jr., Edwin Mampe, Jr.

The following people merit special recognition for their contributions to the preparation of this report. Many others from Government agencies, foundations, educational institutions, industry, and professional organizations gave freely of their time and talents to make this report possible. Space limitations preclude listing them all, but whatever merit the report may have is due in large measure to their efforts.

AEC .... Paul C. Bender, Secretary to the Commission
Robert E. Hollingsworth, General Manager
John P. Abbadessa, Assistant General Manager, Controller
Victor Corso, Deputy Assistant General Manager, Controller
James L. Liverman, Assistant General Manager for Biomedical & Environmental Research and Safety Programs
John M. Teem, Assistant General Manager for Physical Research and Laboratory Coordination
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Support Services:

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Marian C. Fox, Assistant Chief, Editorial Branch, Technical Information Center, Oak Ridge
Hazel E. Whitaker, Educational Publications Officer, Publications and Reports Branch, Office of Information Services
Members of the Division of Headquarters Services

EPA .... Kurt E. Yeager

EPO .... Advisory Council on Energy Research and Development
William T. McCormick, Jr., Staff Assistant

GAC ..... General Advisory Committee (to the Atomic Energy Commission)

NSF ...... Paul F. Donovan, Director, Office of Energy Research and Development Policy

OMB ...... John C. Sawhill, Associate Director for Natural Resources, Energy & Science
Hugh Loweth, Energy and Science Division
Patricia Mooney, Budget Examiner
James A. Walker, Management Associate

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