V. RECOMMENDED PROGRAM

A. COAL GASIFICATION

It is contemplated that R&D for low-B.t.u. gas will be of importance (a) to provide for clean electric power generation at high efficiency, and (b) to meet industrial demand for gas. These functions are expected to help curb excessive reliance on imported oil and LNG by enabling high-sulfur coals to be used for power generation and other purposes without pollution.

This program involves research and development directed toward fluidized-bed, fixed-bed, and entrained-flow gasifiers. Pilot plant demonstration will be constructed to handle up to 50 tons of coal per hour. The plants will range from 120 to 200 megawatts generating capacity. Each will include a gas cleanup system to remove sulfur and particulate matter. In addition development is proceeding on a hot gas cleanup system, operating at gasification temperatures in order to increase efficiency and improve the economy of the processes.

Most of this program was initiated in FY 1973; thus the projects are still in an early stage of development. However, some significant results have already been obtained, including (a) completion of design of a 1200-pound-per-hour fluidized-bed gasifier; (b) conceptual design of an atmospheric pressure, entrained-flow gasifier for a 550 megawatt combined power system; and (c) completion of design of a laboratory scale pilot plant for removal of sulfur from fuel gas by means of a fused salt scrubber system.

In FY 1975 in conjunction with industry funding for these purposes, the low-B.t.u. gasification will move forward, with pilot plant construction beginning in FY 1975-76 capable of converting 50 tons of coal per hour to low-B.t.u. gas.

The Federal Government share of this recommended program for major program elements is approximately 2/3 Federal and 1/3 private. The rounded Federal funding levels in millions of dollars are:

FY 1974	FY 1975-79	Baloncerts Complete	Total
25.5	574.8	40.2	615.0

Two co-funded pilot/demonstration plants are planned with initial operation estimated for the FY 1977-78 period, thereby providing a basis for wide commercial application by the early 1980's.

As with the high-B.t.u. gasification program, the development of reliable and feasible hardware for plant operation requires investigation of a variety of processes, with the possibility that different processes will be optimum for different coals.

A research effort for low-B.t.u. clean fuel gas from coal will also be integrated with research on gas turbines. The bulk of the research will be expended by contract, supplemented by work in Government laboratories. The major efforts will seek to develop low-B.t.u. gasification techniques as an outgrowth of past Departmental program. A single commercial-size gasifier is capable of producing sufficient low-B.t.u. gas for a 1000-

megawatt powerplant, and the gasifier and its associated cleanup equipment can be tailored to a conventional plant, a gas turbine, plant, or an advanced gas-turbine/steam-turbine plant.

The minimum program drops a pilot/demonstration plant, five sub-process efforts, one high-temperature clean-up effort but retains supporting lower-level R&D. Commerialization is delayed until at least the late 1980's.

The maximum program increases effort on supporting process R&D, initiates the immediate construction of two additional pilot/demonstration plants (30 to 100 MWe) and initiate detail design and procurement of a 300 MWe to 500 MWe demonstration/commercial plant at an existing utility. Steam boiler design to efficiently utilize low-B.t.u. gas fuel is made and fabrication is started. Three additional approaches to high-temperature gas clean-up are initiated. The maximum program delivers commercial application in 1980.

B. GAS TURBINES

(1) Closed-Cycle Gas Turbine for HTGR

As indicated by the already-completed plant conceptual design, the plant will require four identical conversion modules coupled to a single 3000 MWt HTGR. Therefore, the plan for this subprogram is based on a nominal conversion module output of 275 MWe.

Work under this subprogram will be initiated in early FY 1975 with prototype conversion component design studies using information from the conceptual plant design work now available. Preliminary designs will be started on receipt of early conversion module specifications from the AEC.

It will be necessary to support the design activity on the prototype conversion components with a developmental testing program to provide confirmatory design data. This test program will be initiated in early FY 1975 beginning with the more fundamental investigations of helium effects on materials and turbine and compressor blade aerodynamics. This part of the subprogram will include the following investigations:

a. Helium effects on materials in high-temperature components

b. Compressor and turbine single-stage aerodynamics

c. Turbomachinery inlet ducts, scrolls and diffusers aerodynamics

d. Turbine-blade attachment alternatives.

e. Gas-duct valve sealing and reliability

f. Compressor and turbine blade vibratory dynamics

g. Turbine-disc cooling effectiveness

h. Rotor bearings and seals performance

i. Compressor and rotor integrity at overspeed conditions

j. Wear life at turbomachinery mechanical interfaces

k. Full-scale, partial power turbomachinery testing

l. Recuperator and intercooler fabrication development

m. Recuperator and intercooler pressure drop and flow vibration tests

n. Recuperator and intercooler tube attachment friction and wear tests

The results from the component developmental testing will enable completion of the design of the prototype components in preparation for fabrication. Long-lead materials and forgings will be ordered as early as possible. To compress the overall subprogram schedule, the component designs will be frozen prior to the completion of those tests related to service life investigations. Information from these extended tests will be used to modify designs, if necessary, of components for the first operational plant.

The major part of this subprogram is the fabrication of the prototype components, their assembly into the prototype conversion module, the design and construction of the conversion module test facility, and the test of the module at 275 MWe output. The test will be conducted using a fossil fuel-fired helium heater to provide 750 MWt to the conversion system. By including heater controls which simulate the reactor, the plant control system can be developed and tested as well. The conversion system components to be tested are the compressor-turbine unit, power turbine, generator, recuperator, intercooler, and duct valves and controls.

The objectives of the conversion module test program are as follows:

a. Confirmation of all design aspects of the prototype components and performance determination of the complete conversion module.

b. Determination of the interactions between components and the dynamic characteristics of the conversion module.

c. Development of the control system.

d. Development of installation, assembly and remote maintenance procedures and tools.

The 275 MWe conversion module test facility is the controlling element in the overall schedule. This plan assumes that plant conceptual design will be accomplished in FY 1974. Plant preliminary design and long-lead construction planning and work will begin in FY 1975. The facility will be desinged to completely meet the objectives of this subprogram. However, provisions will be included in the design which will enable future testing of improved and higher temperature components, as advances are made in the HTGR operating temperature through planned AEC development. This facility will also be subsequently used to support development of a fossil fuel closed cycle gas turbine plant.

The plan is to operate the pilot demonstration test facility by 1981 generating 275 MWe.

(2) Combined-Cycle High-Temperature Gas Turbine System

Work under this subprogram will be initiated in early FY 1975 with prototype conversion component design studies using information from the six to eight combined cycle (gas-steam) plants that are in operation.

The support effort will be one of laboratory research and development such as water cooling of turbine blades, catalytic combustion; application of advanced materials in the turbine hot end, and the application of specific ceramic materials wherever produced and possible based on the status of technology at the time of construction of the pilot demonstration.

The pilot plant demonstration at the nominal 100 MWe will be component tested, assembled, and put into operation in the 1978-1979 time from.

(3) This double thrust of the 1500°F Helium Closed Cycle Gas Turbine as the power conversion system of a High Temperature Gas Reactor in the Direct Cycle Configuration and the 2500°F Industrial Gas Turbine as the prime power source burning clean fuels in a Combined Cycle configuration should at the pilot or

laboratory-demonstration stage be government funded and then move to a joint venture between Government and the utilities. Commercialization should be almost entirely funded by industry.

(4) The following chart is indicative of the kind of monies required to pilot demonstrate the double thrust in an orderly fashion in millions of dollars.

FY 1975	FY 1976-1979	RUNOUT	TOTAL
41	584	375	1000

C. MHD

The goal of this program is to accelerate the development of MHD power generation. The major component of this program is the development of: (1) an open cycle MHD power system leading to the start of construction of a coal-fired demonstration plant in 1980 and operation in 1985. Smaller program elements are concerned with (2) liquid metal systems and (3) closed cycle systems and are aimed at the operation of a pilot power system in 1983. All three program elements will have large efforts in the area of materials engineering especially during the early years. In the open cycle MHD development there will be considerable emphasis on the US-USSR cooperative MHD program. Preparation for the construction of demonstration plants and prototype systems requires a considerable amount of systems design and analysis and supporting R & D. Major parts of the program especially during the period 1976-1978 will be devoted to the construction of large scale test facilities in order to carry out plasma diagnostics and materials testing under coal-fired commercial plant conditions. Both short duration and long time operation facilities will be constructed. Finally, during the later period of the program, depending on the rate of achievement in the earlier stages, a beginning will be made on the design, cost estimates and schedules for the construction of the coal-fired demonstration plant (open cycle) and prototype systems (liquid metal and closed cycle systems). The appendix gives a complete breakdown of schedule, milestones and cost schedules. The following table summarizes these items:

COST IN MILLIONS*

Program Component	1975			1976			1977			1978			1979			Run Out**		
	O	C	M	O	C	M	O	C	M	O	C	M	O	C	M	O	C	M
Open Cycle	21	26	16	47	59	36	56	67	45	20	37	13	14	39	10	406	370	446
Liquid Metal	4.5	5	4	5	9	4	6	11	3.5	14.2	26	3.7	6.2	26.2	4.7	20	--	25.75
Closed Cycle	2.5	4	.4	2.5	4	.4	3.1	4	.5	2	12	.7	2.4	22.4	.8	20	--	29.3
TOTAL	28	35	20.4	54.5	72	40.4	65.1	82	49	36.2	75	17.4	22.6	87.6	15.5	446	370	552 552

* O - Orderly Program

C - Crash Program

M - Minimum Program

** Run out cost includes demonstration
(Open Cycle) or Prototype
(Liquid Metal and Closed Cycle) Plants

D. POTASSIUM CYCLE

Recommended Program. The foundation of this program is the considerable experience with potassium - vapor power systems for the space program during the 1960's. A complete potassium power system of 150 kilowatt output was successfully operated for over a year. Although small in size, this system was very much like the potassium system required for central-station use.

This background of experience has already shown the technical feasibility of a potassium topping cycle. In early FY 1975, a preliminary design and an economic assessment of a commercial-scale plant by an industrial team (including an architect-engineering firm) will show the economic feasibility. At this time, the key issues are to select a design concept that minimizes technical risk and to shape the program for both rapid progress and minimum financial risk; in several ways, these goals are mutually compatible and mutually supporting.

The technical risks are diminished by use of operating temperatures that have already been successful and through use of existing conventional materials. Clean fuels will be used in the early phases of the program; a separate phase of the program will investigate the clean combustion of coal, the removal of fine particulate matter from the combustion products, and the long-time compatibility of the potassium-containing materials and the coal combustion products.

The potassium components (pump, boiler, turbogenerator, and condenser) will be designed and built in 30 MW modules. These modules are small and thereby of low cost in order to minimize financial risk in the pilot-plant demonstration. These modules are also small enough that they may be built in a factory under controlled conditions and then be shipped to the pilot-plant site. Not only is this factory assembly cheaper than field assembly but also the quality control in the manufacturing process much better, a factor markedly lowering technical risk.

As a means of diminishing the investment and thereby also the financial risk, only the potassium loop will built for the 30 MW pilot plant. The component that condenses the potassium and boils and superheats the water will, of course, also be built, but the steam will merely be condensed by a stream of cold water and then returned to the boiler for reuse. No additional money will be spent for conventional steam components for the pilot plant. Through the modular approach in the program, the step from pilot plant to commercial demonstration can be quick, cheap, and comparatively free of risk. Three boiler modules, three turbines, and three potassium condensers will provide the full 90 MW from the potassium loop; inasmuch as these components will have been successfully demonstrated in the pilot plant, no time or money is required for design or development of these components, and, of course, only two rather than three new copies of each component need be built. Thus, the time, cost, and risk of developing new components can all be saved and the time and money required to proceed from pilot scale to commercial demonstration scale can both be reduced. Following use of clean fuel direct combustion of coal would be added to further increase efficiency.

The funding required for this highly planned program (optimized program, if you will) is shown in Appendix C.

Reduced Funding. In a program having such a refined strategy as this, cost reduction are difficult to achieve; the recommended program is already sequential in nature in order for risk to be reduced. Annual costs may be reduced only through slowing down the program. Construction of the pilot plant could be delayed a year and its construction stretched out a year. Not only would the time for payoff then be delayed but also overall program costs would be increased.

The funding plan for the retarded program is presented in Appendix C.

Accelerated Program. This program offer a good opportunity for program acceleration in the following way: Skip the pilot-plant demonstration. In this way, the time to payoff through commercial use could be decreased by 5 years and total program costs actually decreased.

Inasmuch as the potassium components for the demonstration plant are to be identical with those of the pilot plant, the demonstration plant could just as well be built as the pilot plant if adequate funding were available. The technical risk of success or failure would be no greater in either case, for the components are identical. The financial risk would be higher, of course, because of the larger investment at the time the first testing would begin.

The financial issue is thus the comparative evaluation of the uncertainty of success of the first test and of the certainty of added cost and deferred payoff in the recommended but slower-paced program. Perhaps this balance of risk and gain might be analyzed in some detail during 1975 and a decision reached concerning the preferable path. At this time, the option for acceleration might be kept open through accelerated design effort and small-scale tests during 1975.

The funding plans for the accelerated program are given in Appendix C.

E. FUEL CELLS

The basic thrusts of the fuel cell R&D program are to reduce cost, increase life, and provide greater fuel flexibility. The fuel cell systems which show promise for accomplishing these ends, along with the proposing organizations, are shown in the following table:

PROMISING FUEL CELL SYSTEMS & PROPOSALS RELATING TO SAME

Low Temperature (to 400°F)			High Temperature (1000°F to 2000°F)	
H_2		Methyl	Solid Electrolyte	Molten Carbonate
Acid	Base	Alcohol	(ZrO_2)	
EPA	NASA	EPA	001, NBS	EPA 8 others

The dispersed fuel cell generator and the total energy fuel cell programs should be considered together because they use the same acid hydrogen-air cell configuration and operate in overlapping power regions. The modular nature of the fuel cell emphasizes the underlying unity of the approach. The hydrogen for the cell may come from fossil fuels or nuclear energy. If widespread use of hydrogen occurs, this type of cell becomes very attractive because of its simplicity. The reformer, which produces hydrogen from the promising fuel is a major problem area for this approach. This approach, because of its advanced state, should be pushed to a successful conclusion and may provide the first-generation work-horse fuel cell.

The molten carbonate cell is in the early development stage and has major material problems. If these can be overcome, it would be attractive, particularly for power plant use because it has the potential for using a variety of fuels.

Due to the electrochemical processes involved, hydrogen fuel cells can not reach maximum efficiency using acid cells. The 15% performance advantage of the alkaline fuel cell justifies a program to develop a long-life low-cost alkaline hydrogen-air fuel cell. In addition, silver, silver alloys and perovskites show promise for use as air electrodes in alkaline cells, thus providing a substitute for the expensive and scarce platinum electrodes which are so far required in acid systems. The alkaline cell must, of course, provide for carbon dioxide control.

The methyl alcohol cell uses a cheap, pure liquid fuel (with all its advantages). Bench-model methyl-alcohol cells which have operated satisfactorily have been built. Good methyl-alcohol electrodes can be prepared; the main problem is with the air electrode which is poisoned by methyl alcohol which diffuses through the electrolyte and oxidizes at the air electrode, reducing efficiency. The main initial thrust of this program will be to develop air electrodes which are inert to the alcohol, and to develop methods of preventing alcohol reaching the air electrode. Once these problems are overcome, the methyl alcohol cell development should proceed rapidly to the commercial stage. If successful, the methyl alcohol cell would be expected to have a wide use in both stationary and mobile sources and to provide the second generation "work-horse" fuel cell.

The Office of Coal Research (OCR) has supported research and development in a high temperature (1000°C) solid electrolyte (stablized zirconia) fuel cell which culminated in the production of a 100-watt bench-model fuel cell. The development of this cell is fraught with severe materials problems because of the high temperature involved. However, if successful, it could be utilized with coal gasification to produce electricity at 80% efficiency using dirty gas. The high pay-out of this effort, if successful, qualifies this program for support although high risk is involved.

The proposal of the National Bureau of Standards (NBS) to carry out supporting research and development to develop catalysts and solid electrolytes for the solid electrolyte fuel cell should be considered an integral and necessary part of the development program for this fuel cell.

The recommended funding for the fuel cell program is summarized in the following table:

Program	Funding, Millions						Total
	1975	1976	1977	1978	1979	To Completion	
Acid Hydrogen	4.5	10.3	11.6	15.2	15.3	50	106.9
Basic Hydrogen	2.1	2.7	3.8	3.8	3.8	15	31.2
Methyl Alcohol + Small System Effort	1.4	4.5	7.3	7.4	7.4	0	28.0
Solid Electrolyte (High Temp.)	4.0	5.0	6.0	6.0	6.1	50	77.1
Solid Electrolyte Support	0.9	0.6	0.7	0.7	0.7	4	7.6
Molten Carbonate	Funded under acid hydrogen						
TOTAL	12.9	23.1	29.4	33.1	33.3	119.0	250.8

It may be noted that the envisioned program is broad based with a simultaneous pursuit of a number of fuel cell concepts. This approach is dictated by the high-risk nature of the approach and the realization that no one fuel cell concept is clearly superior at this time. Greatest funding has been placed in the acid-hydrogen area because of the maturity of the program.

For a minimum program the following adjustment is presented for consideration:

1975-1979 Reduce

	Acid Hydrogen	Basic Hydrogen	Methyl Alcohol	Solid Electrolyte	Total
From:	56.9	16.2	28	27.1	128.2*
To :	46.9	15.2	26	25.1	116.8

* $3.6 million for solid electrolyte support is not reduced.

For a maximum program, the recommendation is to search out and fund new or unexploited fuel cell concepts. This would be done by mounting a well publicized "bush-beating", culminating in the awarding of 9 contracts based on a competitive RFP. Contract cancellation would occur at any time technical or economic infeasibility is demonstrated. It is expected that the two most promising concepts would go through the pilot plant stage at a cost of $50 to $75 million over the 5-year period.

F. USE OF WASTE HEAT AND FUEL

In sequence, closed gas turbines will be designed for three sets of service conditions appropriate to three total-energy requirements. The applications are as follows: (1) HUD's Integrated Utility System, (2) DOD's needs for an Energy Depot and for newly established Army bases, and (3) for integration with food processing in the canning industry. Clean fuels (natural gas or clean gas derived from coal) will be the energy supplies. Concurrently, the combustion of coal for this application as well as municipal wastes in combination with either coal or gas.

The recommended program will allow for an orderly development of waste-fuel technology by 1981. A maximum program would allow for development and demonstration of additional competitive processes, but would, at best, speed full implementation of waste-fuel energy recovery systems by 1 to 2 years. Other strategies such as regulations, tax incentives, educational programs and subsidies would probably have a greater effect in implementing energy recovery from waste fuels. The minimum program would allow for generation of information necessary to establish pollution regulations and develop processes which effectively minimize waste-disposal costs. Minimization of waste-disposal and energy-generation costs, which is a principal objective of the accelerated and maximum programs, would not necessarily be achieved.

The recommended orderly program is paced as follows:

		1976-1979		
	1975	Total	Runout	Total
Gas turbines	7.0	35.0	33.0	75.0
Waste fuels	6.6	44.7	3.0	54.3
TOTAL	13.6	79.7	36.0	129.3

G. LOW-TEMPERATURE CYCLES

In association with those in the solar and geothermal programs, the required characteristics of the power conversion system will be studied and defined. Then development of a 25 MW pilot system will be undertaken.

Although no improvement in efficiency of steam power plants is achievable through use of bottoming cycles, the capital cost of the steam power plant might be decreased. At present, the maximum power achievable with a single steam turbine is limited by the centrifugal stress at the base of the very long turbine blades required for passage of the low-pressure steam at the turbine exit; in the winter, the steam-exit temperature might be only 60 or 70°F. For the bottoming cycle, a working fluid would be selected that has a substantially higher vapor pressure at these temperatures. The relief in turbine-blade stress achieved in this way might permit 3000MW to be generated by a single retating unit; the resulting economy of scale will primarily benefit nuclear power stations. A design study will be made to quantify these cost benefits.

Recommended program costs are given below:

		1976-1979		
	FY 1975	Total	Runout	Total
Orderly	1	18	30	49
Maximum	3	90	100	193
Minimum	0	0	0	0

If a minimum program is required for Energy Conversion Techniques, no effort is recommended in this area because of its low priority.

H. ADVANCED CONCEPTS

The goal of this subprogram is to support the investigation of promising new energy conversion methods at the basic research and development level, for it is from these types of efforts that future energy conversion systems will evolve.

An orderly, level of effort, program of $5 million per year over the next five years is recommended. The following table summarizes costs for each program segment at the recommended funding level:

Element	FY 1975	FY 1975-1979 (Total)
CO_2 Cycle	2.0	10.0
Thermionics	1.3	6.5
Advanced Thermoelectric Materials	0.7	3.5
Other	1.0	5.0
	5.0	25.0

Until technical feasibility and/or suitability for commercial application is adequately demonstrated, increased expenditures over the recommended program in a "crash" program probably would not contribute significantly to accelerating the application of these converters to the commercial energy economy.

An alternate minimum program of two million dollars per year through FY 1979 would severely limit the number of advanced conversion methods that could be investigated.

I. ENABLING TECHNOLOGY

(1) Superconducting electrical machinery

The recommended program emphasizes the development of a.c. superconducting generators but includes concurrent efforts on auxiliary equipment such as large-scale reliable helium refrigerators and transfer systems, multimegawatt superconducting transformers and larger d.c. motors. Additionally, the program would inlcude development of superconductors in the form and shape and possessing the characteristics necessary to technology.

The goal of the program would be to design, construct, and test a 100 MW, 3600 rpm, a.c. generator whose electrical pera,eters such as voltage, impedance, and time constants would match the needs of existing power distribution systems. The areas of study and development would include machine analyses, materials development, stator and rotor development, cryogenic and refrigeration systems, manufacturing techniques, and instrumentation.

The recommended program would develop the technology through to the construction and testing of a 100 MW generator by late FY-1979. At this point in time, commercial interest in further development should be assessed to determine the value of further federal investment in the technology. A major portion of the recommended program would be performed by industry under contract to the government with cost sharing in the later stages.

The "maximum" program would also provide for commercial testing and preliminary designs for larger capacity equipment.

The minimum program would be limited primary to work on the 100 MW generator and deemphasize work on auxiliary systems.

(2) Materials

The recommended underguiding program on materials will bridge the gap between short-term materials development and multidirectional basic research. The recommended program will be continuing in nature on a level-of-effort basis and will be carried out where the expertise resides — universities, government, laboratory, not-for-profit and commercial institutions.

The program would provide new materials for MHD, heat exchanger, gas turbine, and other applications to withstand high-temperature, high-pressure, high-velocity, corrosive and erosive environments, and thermal shock and thermal cycling. Attention will be directed to pertinent engineering properties including diffusion characteristics in candidate materials of components of the separated environments in heat exchangers application. The effects, kinities, and mechanisms of attach of micro impurity, constituents, slags, and seeds on candidate materials will be investigated.

Ceramic and composite materials for first-row and inlet Blades for high-temperature gas turbines (2500°F) will be investigated as will improved materials will be sought for low-pressure steam turbine blades and for generator retainer rings including their behavior at temperature and under stress.

Since this is a level-of-effort activity, the recommended program is now a matter of considered judgment as opposed to being based on a firm calendar of milestones. It is expected that it is continuing in nature beyond 1979, the last year of the projection. The "maximum" program represents the total of meaningful proposed requests where as the minimum represents the smallest viable program which could contribute to the technology.

Recommended Federal Funding

	75	76	77	78	79	75-79
Sub-program (a)	5.0	5.0	5.0	8.4	4.0	27.4
Sub-program (b)	3.0	4.0	6.0	6.0	6.0	25.0
Total	8.0	9.0	11.0	14.4	10.0	52.4