CONVERSION TECHNIQUES. SUBPANEL REPORT VI USED IN PREPARING THE AEC CHAIRMAN'S REPORT TO THE PRESIDENT

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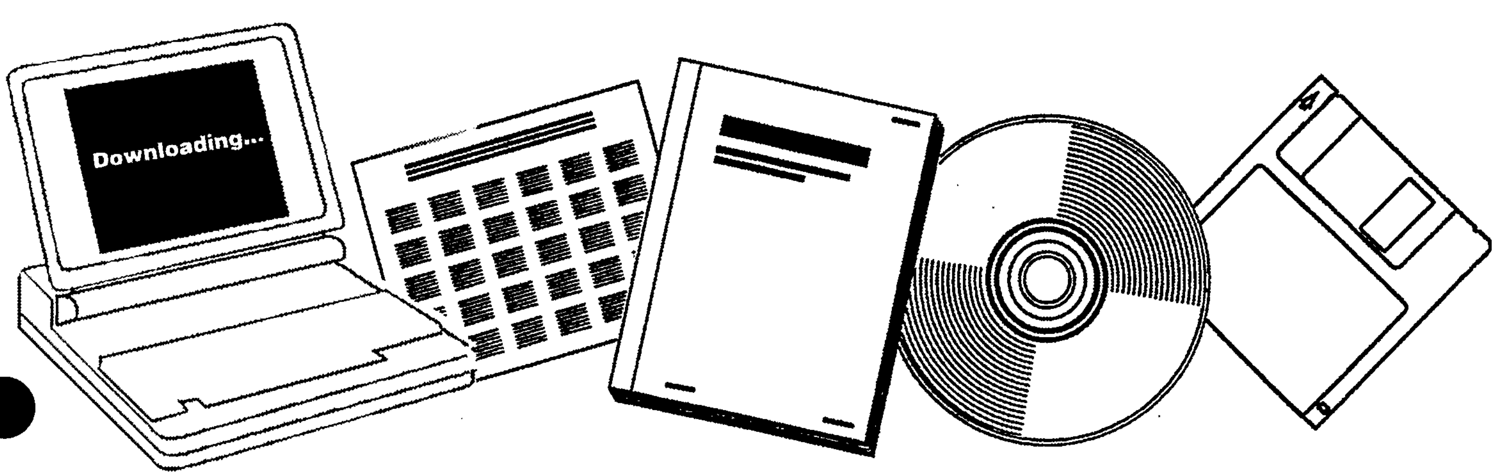

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CONVERSION TECHNIQUES

R & D PROGRAM

FY 75-79

Submitted by Subpanel VI
November 13, 1973

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Prepared for the Chairman, AEC, in support of her development of a comprehensive Federal energy R & D program to be recommended to the President on December 1, 1973

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1. GOALS AND OBJECTIVES

The importance of improved techniques for energy conversion is reflected in the following statistics: At present, U. S. residents spend about $40 billion a year for electric power. Our energy-use rate for production of power is 2×10^{16} BTU per year, the equivalent of nearly 1 billion tons of coal or 20,000 tons of uranium each year. Of this input energy over half (about 10^{16} BTU/yr) is wasted and adds to thermal pollution of our waters; the quantity of rejected heat is more than sufficient to heat every residence in the Nation. In addition, construction of new power plants is estimated to total $1000 billion during the remainder of this century.

Fossil steam power plants are the product of a very mature technology that has plateaued at an efficiency of 40 percent. Clean fuels for these power plants are growing scarce, and our means for burning coal are not yet socially acceptable. Present nuclear power plants are 32 percent efficient and are therefore large thermal polluters.

Therefore, improved energy conversion techniques for the reliable generation of electric power and for energy conservation are of great importance to our Nation, and the goals of this R & D program are to (1) increase the efficiency of use of indigenous energy supplies (coal and uranium as well as new, alternate energy sources), (2) to reduce the environmental impact of this power production, and (3) to reduce the capital cost for construction of new power plants.

For the purpose of reaching these goals, the following eight objectives were established:

(1) Coal Gasification. To develop processes for the production and use of clean low-BTU gas from coal in central power stations.

(2) Gas Turbines. To increase the overall efficiency and reliability of power generation by developing high-temperature gas-turbine systems.

(3) MHD. To increase the overall efficiency and reliability of power generation by developing MHD power systems.

(4) Potassium Topping Cycle. To increase the overall efficiency and reliability of power generation by developing potassium-vapor topping systems.

(5) Fuel Cells. To develop efficient and economical fuel cells for power generation.

(6) Use of Waste Heat and Fuel. To develop power systems for economical use of heat and fuel presently wasted.

(7) Advanced Concepts. To evaluate, to investigate, and ultimately to develop advanced concepts for energy conversion.

(8) Enabling Technology. 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.

An implicit constituent of these objectives is to minimize the environmental impact of power generation.

These eight objectives represent a significant narrowing of the range of options considered. Under the pressure of severe budgetary constraints, the R & D originally proposed on Low-Temperature Cycles was deferred and converted instead to a study under Advanced Concepts. Further, the Use of Waste Heat and Fuel was confined to the use of solid waste for power generation.

Among energy conversion techniques in these eight objectives, the following three priorities were assigned:

If a large advance in technology is to be achieved that involves both long time to financial payoff and substantial technical risk, the Government must be a heavy financial contributor. For those technology programs affecting public welfare (such as pollution reduction) rather than financial gain for the power industry, the Government must carry the major share of the financial burden.

3. PROGRAM BUDGET

The energy conversion R & D budget amounts to $755 million for FY (75-79) with the FY 75 expenditure totaling $89 million. The $89 million includes $50 million for the low BTU gasification subprogram which has been already obligated. Table 1 (attached) summarizes details for each subprogram.

4. SUBPROGRAMS - DESCRIPTION, BENEFITS AND BUDGET

GASIFICATION (LOW BTU)

Each commercial power generation plant or industrial application of low BTU gas from coal will release current premium fuels such as natural gas or oil for other higher priority usages.

The goal is for low BTU gasification pilot/demonstration size (20 to 50 MWe) combined cycle systems utilizing present technology and consuming all ranks of coal which are scheduled for operation in the 1976-1979 time period operating in a non-polluting mode. These plants will supply operating and economic data so that participating utilities can proceed with the construction of a multiplicity of plants with confidence. At least 3 improved technology pilot scale gasification reactors for inclusion in future improved systems will be constructed and operating by the end of this time period.

Selected sub-process improvements for incorporation in later systems will be developed. Improved gas turbine efficiency increases are anticipated from other energy initiatives. This total effort is based on continuing cooperative funding by industry (2/3 Federal - 1/3 industry) and those major program elements not so funded will be deemphasized or eliminated.

This is a reasonable program of high impact on future electric power generation with no known major technical obstacles. The plant combined cycles systems will operate at initial efficiencies over 40% as compared to 35% conventionally and produce power later at efficiencies approaching 50%; however, the relative economics and growth potentials of such systems can only be proven by early construction and operation at pilot/demonstration scale plants.

Commercial exploitation of the developed low BTU system 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
Electrical Power	32.9×10^6 MWH e	1150×10^6 MWH e
Q energy released for priority uses	0.28×10^{15} BTU	9.8×10^{15} BTU
Q saved by high efficiency	0.014×10^{15} BTU	$0.49 - 0.9 \times 10^{15}$ BTU

Budget ($ Millions)

	1975	1976	1977	1978	1979	Total
Federal	50	60	80	35	25	250
Industrial	(15)	(25)	(35)	(25)	(25)	(125)

Construction of pilot/demonstration plants shape the funding towards early heavy expenditures tapering toward 1979 with the peak in 1977. Lag in cooperative funding capability of industry tends to front load the Federal contribution.

HIGH TEMPERATURE GAS TURBINES

For fossil-fueled gas turbines, two programs are planned, viz., (1) high-temperature gas and steam turbine combined cycle and (2) closed gas turbines to supply waste heat.

The combined cycle is entering utility service this year and will achieve an efficiency of 40 percent. The crucial improvement needed for the system is to raise system efficiency to 50 percent by increasing turbine-inlet temperature to 2500°F. Improved air-cooling of the turbine and, in particular, liquid-cooling must be investigated and developed. Ceramic materials for turbines will be also investigated under the Enabling Technology subprogram (q.v.). Low-pollution combustion will also be investigated as well as the use of a pressurized furnace for the steam boiler as a way to both reduce system cost and increase efficiency. The higher temperature turbines will be tested in the laboratory and demonstrated in 1979 in a 100-MW demonstration plant at a utility's power plant; a system efficiency of 50 percent is anticipated.

This gas-turbine development will be carried out by industry under contract to the Government. Industrial contribution to the 100-MW demonstration plant is expected to be 50 percent. Power plants incorporating this advanced technology will enter service in the mid-1980's. Energy savings in the year 2000 will amount to 2×10^{15} BTU per year, having a value of $2 billion a year at $1 per million BTU.

1975-77 Design, build and test high-temperature turbines.

1975-76 Design, build, test catalytic, surface, and reformed-fuel low-pollution combustors.

1976 Economic study of pressurized furnace.

1976 Design 100-MW demonstration power plant.

1977-79 Build 100-MW power plant.

At present, high-grade fuels are burned and electric power is consumed in various applications solely for the purpose of providing heat. Integration of power generation with the supply of heat can yield enormous energy savings. Because the total demand for heat is beyond what power generation can provide, the market for waste heat can, from the point of view of power generation, be considered limitless.

In realization of this goal, the problems are (1) to minimize the cost of distributing the waste heat by generating the power near the site at which the heat is required, and (2) to heat the transport fluid (water) to 400°F while maintaining a high efficiency of power generation. The closed fossil-burning gas turbine is well suited to this service because of its suitability to produce powers from 1-100's MW close to the site of heat use, its constant, high efficiency at part power, its ability to burn various fuels (including municipal or industrial waste), its maintenance-free operation, and its ability to heat water to 400°F without a penalty in efficiency. The potential energy savings are 4-8 x 10^{15} BTU/yr in the year 2000, depending on the speed of entry into the marketplace.

The schedule of events and funding are given below:

1975 Design 1-MW power plant

1976-77 Build test models of components and power plant

1978 Test the power plant

1979 Continue power plant tests. Procure additional power plants for use by HUD in energy-conserving housing developments.

Cost in Millions

FY	1975	1976	1977	1978	1979	Total
Funds	15	65	53	50	42	225

MAGNETOHYDRODYNAMICS (MHD)

There are three MHD concepts: 1) open cycle, 2) liquid metal closed cycle, and 3) closed cycle plasma. An open cycle generation system is ideally suited for fossil fuel operation (including coal) while the closed cycle systems are better adapted to nuclear heat sources. All systems when combined with conventional MHD cycles, offer significant benefits which include:

- high efficiencies (55-60%)
- fuel and dollar savings*

  1×10^{15} BTU in year 2000

  1 billion dollars in year 2000
- direct coal-fired systems
- non-polluting systems

  NO_x - 1/9 EPA standards

  SO_x - 1/20 EPA standards

  Water - nil

The goal of the MHD program is to accelerate the development of these highly efficient, non-polluting systems. The open cycle segment of the program (the largest) will lead to the construction of a coal-fired demonstration plant in the 1980's and operation in about 1987. Smaller program elements are planned for the closed cycle systems but will

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* Assuming 28.9×10^{15} BTU total electric demand from fossil sources in 2000; and fuel costs of $\$1/10^6$ BTU.

lead to the proof of technical feasibility and design of prototype systems. During the FY 1975-1979 period the program will be devoted to: 1) component and materials development and testing, 2) system analysis and design, and 3) facilities design and construction (large scale generator and long endurance materials test facilities). The generator and materials test facilities amount to about 60% of the FY 75-79 costs and are key features of the program. In effect, they replace many aspects of a conventional pilot plant. Also there will be considerable emphasis on the utilization of existing USSR MHD facilities (25 MW and 250 KW plants) and expertise through the ongoing US-USSR Cooperative Program.

Under Government management, the FY 75-79 program will be implemented by contract to a mix of national and university laboratories and industrial organizations already involved in MHD R & D. Scientific and engineering expertise and manpower are readily available for the design, construction and operation of test facilities. As evidenced by previous support ($8 million), industry can be expected to provide a significant portion of the funds necessary to bring about commercialization of MHD. Early industrial involvement will amount to some $20 million through FY 79 by the Electric Power Research Institute and expand to at least 30-50% of the cost of a demonstration plant (utilities).

The following table summarizes the suggested Government R & D budget:

<u>FY Cost in Millions</u>

1975	1976	1977	1978	1979	Total 75-79
10	19	22	22	22	95

POTASSIUM TOPPING CYCLE

Potassium vapor generated at 1400-1500 °F is expanded in a turbine and then condensed at 1100 °F, the heat of condensation being the heat input to a conventional steam power plant. Overall efficiencies of 50-55 percent appear practical, about a 30 percent increase over the best fossil plants today. Both energy consumption and thermal pollution would be reduced accordingly.

The low operating temperatures of this power plant might make feasible the direct combustion of coal without atmospheric pollution. In a fluidized bed, the combustion temperatures might thereby be limited to maximum values of 1600-1700 °F, thereby both avoiding NO_x formation and permitting limestone or dolomite to capture the sulfur. Competitive concepts using clean fuel must exceed 60 percent efficiency in order to achieve the same efficiency between coal pile and busbar.

Operation of a complete potassium-vapor system fired with natural gas for over a year has already demonstrated the feasibility of the concept. The following sequence and timetable of events are planned:

1974	Power plant preliminary design and economic assessment by an architect-engineering firm.
1975-1979	Design and build a 30 MW potassium power system as a pilot plant demonstration using clean fuel.
1979-1981	Operate the 30 MW pilot plant.
1980-1984	Build two additional 30 MW potassium modules and add them to the pilot plant. Build and add steam power-generating equipment. Demonstration plant output, 300 MW; potassium output, 90 MW.

<u>1985</u> Start full commercial operation of the 300 MW plant.

1977-1981 Build and test a pilot-scale fluid-bed furnace for later incorporation into the demonstration power plant.

The following budget is required:

Fiscal Year	75	76	77	78	79	75-79
R&D	3	7	7	7	7	31
Pilot Plant (C of F)	0	8	14	9	3	34
Total	3	15	21	16	10	$65M

This entire program will be performed by industry under government contract. Both the pilot plant and the demonstration plant would be installed at the site of a cooperating utility. Although the government would pay for the plant design and its economic assessment, both the equipment manufacturer and the cooperating utilities are expected to pay 25 percent of the pilot plant cost and one-half the cost of the demonstration plant.

Following demonstration in 1985, the installation of this class of power plant would begin and could reach 150,000 MW by 2000. Accordingly, fuel savings would amount to 10^{15} BTU per year and $1 billion* a year at that time.

*Based on fuel cost of $1 per million BTU.

CONVERSION SYSTEMS - FUEL CELLS

Fuel cells are simple devices which convert chemical energy directly to electrical energy with efficiencies which are presently about 60% and ultimately may approach 80% with essentially no environmental pollution. They are modular in nature and may be supplied in a variety of sizes varying from fuel cells for use in individual houses (5 KW giving "total energy" capability) to fuel cells for use in substation power plants (150 MW). Fuel cells are quiet and have essentially instantaneous response to load variation, high efficiency at partial load operation, heat rejection to air and automatic operation. Fuel cells, an emerging technology with demonstrated technical feasibility, require R & D to solve three major problems: cost, life, and limited fuel flexibility.

The proposed program is aimed at solving these problems for the following five promising fuel cells systems: acid hydrogen, basic hydrogen, methyl alcohol, solid-electrolyte and molten carbonate. The envisioned program is broad based with a simultaneous pursuit of a number of fuel cell concepts because of the high risk nature of the approach and the realization that no one fuel cell concept is clearly superior at this time. Greatest funding will be placed in the acid hydrogen area because of the maturity of the program and possibility of early commercialization. Basic hydrogen has been supported because it has the potential of being 15% more efficient than acid hydrogen with simultaneous use of less expensive electrocatalysts. The methyl alcohol cell is attractive because of its potentially high thermodynamic efficiency plus the use of a pure, cheap, easily available liquid fuel. The solid electrolyte and molten carbonate cells operate at high temperature and have the potential for using dirty fuels with good efficiency.

The program provides the following by the end of 1979:

1. Build and test one 7 KW methyl alcohol prototype fuel cell.
2. Build and test dispersed power plants (2 to 5 MW, 1976; 20 MW, 1977).
3. Commercially demonstrate the acid-hydrogen fuel cell on site system (40 KW Field Unit).
4. Pilot test hydrogen fuel cells in the integrated total energy system.
5. Build 10 KW basic hydrogen prototype fuel cell.
6. Build a 10 KW solid electrolyte fuel cell and begin testing.
7. Limited search for new concepts.

At present, industry is supporting the acid hydrogen cell development at a rate of about 15 million dollars per year and the methyl alcohol cell at a level of about 2 million dollars per year. The Electric Power Research Institute (EPRI) is spending about $2 million per year in fuel cells. The other concepts are being supported at low levels by a number of organizations. The projected developments on this program are predicated on the assumption that industry (which has solicited Government participation) will contribute at least $2 for every $1 that the Government furnishes.

Progress in the fuel cell area is limited only by the availability of funding. If platinum is required as the electrocatalyst in fuel cells, then large scale fuel cell production will require low platinum loadings. However, the development of less expensive and more available electrocatalysts is an integral part of this program.

The proposed budget is:

1975	1976	1977	1978	1979	75-79
5.5	9.5	17	22	26	80

Fuel cells are applicable to the whole spectrum of sizes varying from use in the home to use in power plants. Fuel cells may replace the internal combustion engine in many applications, thus the following energy savings are projected:

Q (10^{15} BTU) (Savings)

	Residential	Commercial	Power Plants	Cars	Total
1985	1.2*	0.3	0.3	0.3	2.1
2000	9.0*	2.5	1.0	4.0	16.5

* Integrated system.

CONVERSION SYSTEMS - USE OF WASTE FUELS

Half of the energy generated in the United States is wasted; this contributes to accelerated depletion of our energy resources, thermal pollution of our waters, and degradation of air quality. In addition, municipal, industrial, agricultural, forestry, and mining wastes are posing solid waste disposal problems which are increasingly difficult to solve. Much of the solid waste can be burned directly to produce clean energy or can be converted to clean fuels. Programs to develop and utilize these energy sources are described below:

Processes will be developed and demonstrated to economically recover clean energy from municipal, industrial, agricultural, forestry, and mining wastes. The processes considered include waste combustion, gasification, liquefaction, and biochemical conversion.

The following program will be carried out: (1) processing and combusion of wastes as auxiliary fuels in commercial, industrial and utility boilers - 1978, (2) processing and combustion of waste fuels in fluid bed combustors with gas turbine-electrical energy recovery - 1978, (3) thermochemical conversion of wastes to clean gaseous, liquid or solid fuel - 1980, (4) biochemical conversion of wastes to liquid fuels - 1981. These technologies will be demonstrated under joint programs with industry and local governments, who are developing new waste disposal processes. Emphasis will be placed on equipment development and process modifications which are needed to optimize energy recovery.

Budget

Fiscal Year	75	76	77	78	79	Total
Cost in Millions	1.5	2.6	2.3	1.9	1.7	10.0

There are indications of wide support of waste disposal-energy recovery processes by both industry and local government. In fact, the success of the above programs is predicated on the assumption that they will put in at least $2 for every $1 of Federal funds. At least 5 utilities have firm plans for firing municipal wastes as an auxiliary fuel in their boilers. However, the newer, higher level development cost processes (fluid bed combustion, thermochemical conversion and biochemical conversion) will probably require partial support by Federal funds through at least pilot scale operation. Many localities face critical solid waste disposal problems. If development of new technologies are not implemented by Federal funds, older processes which do not recover energy will be installed and the energy which could have been recovered will be lost during the 15 to 20 plant year life.

Benefits of the proposed developments would include: (1) recovery of over 10^{15} BTU/year of energy by 1985, (2) economically and environmentally acceptable disposal of solid waste and, (3) a reduction in air pollution.

ADVANCED CONCEPTS

A five year experimental and analytical program to conduct applied research and engineering development on a number of promising advanced energy conversion methods and concepts for eventual use in high efficiency central station, decentralized and smaller power plants. A number of energy conversion methods and concepts including Feher (CO_2) cycle, thermionics, thermal oscillator, thermogalvanic cells, advanced thermoelectric materials and low temperature cycles have been identified as having the potential for higher energy conversion efficiencies compared to existing systems.

Feher (CO_2) cycle and thermionic conversion would receive the highest priority for investigation because of their impact on large power systems. Other conversion techniques such as thermal oscillators, thermogalvanic cells and advanced thermoelectric materials are more applicable to increasing the conversion efficiency of small power plants and hence would receive a lower priority. Other advanced cycles such as the organic Rankine would receive analysis and assessment for use as low temperature/bottoming cycles.

The application date of these energy conversion methods to commercial power production in central station plants would be no earlier than the mid-1980's due to their advanced nature. It is possible that new small power plants would be commercially available in the late 1970's. All of the potential advantages of these new technologies cannot be anticipated and therefore, the specific time of application for the small power plants is difficult to determine.

The CO_2 cycle system appears to offer efficiencies for central station power plants in the mid-40% range for temperatures of about 1200 °F. If the potential of thermionic conversion is achieved, topping cycles can be added to decentralized power plants that will raise conversion efficiencies from present values of 30 to 40% to the range of 40 to 50%. The efficiency of a thermionic conversion system is relatively independent of power level, thus thermionics may be applied to various size energy conversion systems. The other conversion methods have demonstrated efficiencies, in laboratory scale experiments/devices, of as high as 30%.

Industry has made only a minimal investment in this area due to the advanced nature of and long time to payoff for these conversion methods. It is believed that this situation will continue to exist until more specific development results are available from the proposed investigations.

This program does not involve large pilot or demonstration plants but rather applied research, engineering development and analysis of new energy conversion cycles and methods therefore does not involve any roadblocks to implementation.

The recommended funding levels are as follows:

Cost in Millions of Dollars

	FY 75	FY 76	FY 77	FY 78	FY 79	Total
Advanced Concepts	2.0	2.0	2.0	2.0	2.0	10.0

Each of the above energy conversion systems posses unique characteristics and attributes that, if successfully developed, could make significant contributions in the future toward the nation's developing energy crisis. The investment risks are minimal compared to the potential return.

ENABLING TECHNOLOGY

This subprogram has two major thrusts: (1) the development of a 100 MW ac generator using superconductor technology, and (2) a continuing undergirding materials R&D program which is focused on high temperature aspects of materials performance in specific applications and is intermediate between short-term development and multi-directional basic research.

Industry has already constructed 5MW laboratory scale ac generators. The next step is to go to 100 MW before advancing to 600-1000 MW machines. No scientific breakthroughs are required; however, considerable engineering development is necessary. The development of electrical machinery using conventional approaches appears to have been maximized and with the advances now being made in superconductor technology, e.g., higher temperature superconductors, this approach is increasingly attractive.

The proposed effort to construct and test a 100 MW ac generator will be carried out primarily by contract with industry from which substantial cost sharing can be expected. The benefits to be derived from this system's development are: increased conversion efficiency (up to 1% for large installations), circumvention of size limitations of components which may be shipped from factory to installation site, and avoidance of foreign competitors from capturing future markets for electrical machinery. The principal risks/uncertainties center around the complexity of the envisioned system and thus its acceptibility to industry and the utilities.

In most new technologies, the development of new materials is the key to eventual success. Advanced conversion concepts (higher power, higher temperature) will require materials which are now beyond the current state-of-the-art. For example, gas turbines with 2500 °F inlet temperatures will require new vane and first row blade materials. MHD will require special materials for ducts, electrodes, and insulators. High temperature heat exchangers will require high strength materials resistant to thermal shock and cyclic fatigue and which will minimize inter-diffusion of contaminants from one working fluid into the other. The effect of micro impurities in hot working fluids on the long term properties of high temperature materials is poorly understood and in some cases not at all. There is a need not only for new materials but also a more complete bank of engineering data on existing materials to allow prediction of long-term reliability. This is a level-of-effort activity to permit study of only the most obviously important problems and will be conducted in those institutions wherein the expertise lies. The benefits to be derived include increased efficiency, increased reliability, and reduced down time of existing systems, reduction of environmental problems (e.g., inter-diffusion of contaminants), and in the case of new technologies, possibly a go-no-go determination. The budget for the program is:

FY Cost in Millions

75	76	77	78	79	Total 75-79
2	3	5	5	5	20

TABLE 1

ENERGY CONVERSION TECHNIQUES R&D BUDGET

(cost in millions)

Subprogram	FY 75	FY 76	FY 77	FY 78	FY 79	Total FY75-79
1. Coal Gasification (Low-BTU)	50	60	80	35	25	250
2. High Temperature Gas Turbines	15	65	53	50	42	225
3. MHD	10	19	22	22	22	95
4. Potassium Topping Cycle	3	15	21	16	10	65
5. Fuel Cells	5.5	9.5	17	22	26	80
6. Waste Fuel	1.5	2.6	2.3	1.9	1.7	10
7. Advanced Concepts	2	2	2	2	2	10
8. Enabling Technology	2	3	5	5	5	20
Total	89.0	176.1	202.3	153.9	133.7	755.0 345 410

- no breakdown by op, eq, const
- no environ. stmt.

CONVERSION TECHNIQUES

I. Overview

A. Introduction

B. Summary

C. R&D programs

1. Coal Gasification

2. Gas Turbines

3. MHD

4. Potassium Topping Cycle

5. Fuel Cells

6. Use of Waste - Heat and Fuel

7. Low-temperature Cycles

8. Advanced Concepts

9. Enabling Technology

II. Status of Technology

A. Coal Gasification

B. Gas Turbines

C. MHD

D. Potassium Topping Cycle

E. Fuel Cells

F. Use of Waste - Heat and Fuel

G. Low-temperature Cycles

H. Advanced Concepts

I. Enabling Technology

III. Rational For Government Involvement

IV. Priorities among objectives

V. Recommended Programs

A. Coal Gasification

B. Gas Turbines

C. MHD

D. Potassium Topping Cycle

E. Fuel Cells

F. Use of Waste - Heat and Fuel

G. Low-temperature Cycles

H. Advanced Concepts

I. Enabling Technology

VI. Implementation Plan

A. Coal Gasification

B. Gas Turbines

C. MHD

D. Potassium Topping Cycle

E. Fuel Cells

F. Use of Waste - Heat and Fuel

G. Low-temperature Cycles

H. Advanced Concepts

I. Enabling Technology

SUBPANEL VI

CONVERSION TECHNIQUES

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National Aeronautics and Space Administration

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Prepared for the Chairman U. S. Atomic Energy Commission in support of her development of a comprehensive Federal energy research and development program to be recommended to the President on December 1, 1973.

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