I. OVERVIEW

A. INTRODUCTION

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 could evaporate 5 million acre - feet of water each year. In addition, construction of new powerplants is estimated to total $100 billion during the remainder of this century.

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

Therefore, improved energy conversion techniques for the reliable generation of electric power are of great importance to our nation, and we must find ways to (1) increase the efficiency of use of our 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 powerplants.

For the purpose of reaching this goal, the following nine 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) Low-temperature Cycles. To increase the overall efficiency and reliability of power generation by developing low-temperature power systems using organic fluids and/or ammonia.

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

(9) 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 nine objectives represent a significant narrowing of the range of options considered. Thus, R&D effort is recommended in each of the nine areas although priorities among the nine areas were also assigned.

B. SUMMARY

The recommended Conversion Techniques program includes:

(1) An R&D effort in Low Btu Coal Gasification to provide two pilot/demonstration scales (approximately 50 MWe) operating by 1977-78 and commercial scale by 1983.

(2) Gas Turbine Development: closed-cycle (1500°F - Helium for HTGR application) to be pilot plant demonstrated by 1982 and high-temperature open-cycle (steam-combined cycle) to be demonstrated by 1978 with increased efficiencies in the mid 0.40 range.

(3) Accelerated development of (1) open-cycle, (2) liquid metal closed-cycle, and (3) closed-cycle plasma MHD concepts. Open-cycle development will lead to the construction in 1985 of a coal-fired demonstration plant.

(4) Potassium Topping Cycle development with an initial thrust of assembly and test in 1979 of a 30 MW pilot plant power system.

(5) Fuel Cell R&D in this high-risk - high potential payoff area to bring it to the point of commercial application for local use (eg., the home) and substation power plant installation.

(6) Technology development for Waste Heat and Fuels Use in efficient, non-polluting ways.

(7) Low-temperature Cycle (organic and ammonia) development for use with geothermal or solar-thermal energy sources and as bottoming cycles for steam power plants.

(8) Advanced Concepts: R&D on Feher (CO_2) cycles, thermionics, thermal oscillators, thermogalvanic cells, and thermoelectric materials. Analyses, design studies, and small scale tests assessing feasibility are proposed.

(9) Enabling Technology: Development of a 100 MW superconducting conversion (generator) system by 1979 and enabling advanced materials research for high temperature systems intermediate between short term and multi-directional basic research.

RECOMMENDED PROGRAM
(In Millions)

Subprogram	FY 75	FY 75-79	Runout To Completion	Total
Coal Gasification (Low-Btu)	84.5	575.0	40.0	615.0
Gas Turbines	41.0	625.0	375.0	1000.0
MHD	28.0	206.0	446.0	652.0
Potassium Topping Cycles	7.2	87.2	34.0	121.2
Fuel Cells	12.9	131.8	119.0	250.8
Waste Heat/Fuel Use	13.6	94.3	35.0	129.3
Low-Temperature Cycles	1.0	19.0	30.0	49.0
Advanced Concepts	5.0	25.0	30.0	55.0
Enabling Technology	8.0	52.4	60.0	112.4
Total	201.2	1815.7	116.9	2984.7

C. RECOMMENDED R&D PROGRAMS

1. Coal Gasification

The R&D program is directed towards economical and reliable production of clean non-polluting low-Btu gas from coal as a fuel supply for high efficiency combined cycle electric power generation and industrial uses such as process heat and chemical feed stocks. The recommended orderly program provides two pilot/demonstration scale (approximately 50 MWe) plants operating by 1977-78, and commercial scale by 1983. Alternately a minimum program lengthens commercialization to 1987-88 while a maximum program shortens commercialization to 1980.

The following table summarizes the cost estimates for each of these program levels of effort.

COST IN MILLIONS OF DOLLARS

Level	FY 75	FY 75-79	Runout to Completion	Total
Orderly	84.5	575.0	40.0	615.0
Minimum	21.4	250.0	105.0	355.0
Maximum	125.0	900.0	-	900.0

2. Gas Turbines

Several advantages can be realized by combining the closed-cycle gas turbine with the high-temperature gas-cooled reactor (HTGR), and the high-temperature open-cycle gas turbine with a heat exchanger which produces steam for a steam turbine. The nuclear gas turbine (1500°F - Helium cooled) is to be pilot demonstrated by 1982, and the high-temperature combined cycle is to be demonstrated by 1978 with increased efficiencies in the mid forties. These gas turbine programs will lower power costs, reduce environmental effects, and support the optimum use of fuels. Technical (material and design) will be required in the areas of gas turbine combusters, and the hot end of the turbo compressor. The following table in millions of dollars summarizes the orderly-program cost for both open and closed-cycle gas turbine development.

	75	76	77	78	79	75-79	Runout	Total
Open Cycle	35	53	122	152	43	405	20	425
Closed Cycle	6	17	39	60	98	220	355	575
Total	41	70	161	212	141	625	375	1000

3. MHD

There are three basic 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 (including coal) while closed liquid metal and closed plasma systems are better adapted to a nuclear heat source. All systems when combined with conventional cycles offer efficiencies approaching 60%.

The goal of the MHD program is to accelerate the development of these highly efficient cycles. The open cycle segment of the program (the largest) will lead to the construction of a coal-fired demonstration plant beginning in 1980 and starting operation in 1985. Smaller efforts are planned for liquid metal and closed cycle systems and will result in the realization of the design of prototype power systems. All three program elements will address materials questions, system analysis and plant design. Major parts of the program will be devoted to the construction of necessary large scale test facilities to verify concepts, obtain plant design information and to maximize materials performance. The following table summarizes costs for each program segment at the recommended funding level (orderly program).

Cost in Millions

	FY 1975	FY 1976-1979 (Total)	Runout
Open Cycle	21.0	137.0	406*
Liquid Metal	4.5	31.5	20**
Closed Cycle	2.5	10.5	20**
Total	28.0	178.0	446

* Includes demonstration plant.
**Includes only a pilot plant.

4. Potassium Topping Cycle

Heat from coal boils potassium at 1400 - 1500°F, the potassium vapor then being expanded in a turbine to produce power. Condensation of the potassium at 1100°F produces heat that is converted to power in a conventional steam powerplant. Overall efficiencies of 50-55 percent appear practical. The experience of successfully operating a small fossil-fired potassium-turbine system for over a year provides the starting point for this program. The initial thrust of the program will be the assembly and test in 1979 of a 30 - megawatt potassium power system as an economical pilot-scale demonstration of performance and integrity of the design. Then two additional 30-MW potassium modules will be added to the pilot plant in order to produce a total of 90 megawatts from the potassium system; the steam power-generating equipment and auxilaries will also be added in order to produce a total of 300 megawatts of electric power in 1984 for demonstration at full commercial scale.

For the purpose of reducing risk in the program clean fuel will initially be used; direct combustion of coal would be more energy-efficient and will be investigated separately from the 30 MW pilot plant. If fully successful in this separate investigation, combustion of coal in a pressurized fluidized bed will also be demonstrated in the 300 MW demonstration plant.

Overall, the program plan described above produces good progress at minimum financial and technical risk. An accelerated program could gain 5 years' time and save money by operating the complete 300 MW demonstration plant in 1979 rather than in 1984 simply by skipping the pilot demonstration.

The rate of funding could be diminished for each year by merely slowing down the program. Construction of the pilot plant could be delayed one year and its construction stretched out an additional year. The penalties associated with the slower paced program are an increased time for program payoff and an increase in total program costs.

The funding levels associated with the three program paces are given below: funds are in millions. The degree of cost sharing by industry has been estimated, and the industry contribution (about 50%) is not included in these figures.

	FY 75	FY 76-79 (Total)	Runout	Total
Orderly	7.2	80	34	121
Maximum	7.2	95	7	110
Minimum	4.2	56	120	180

5. Fuel Cells

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). The overall efficiency of total energy systems using fuel cells may approach 75 to 80%. 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 fuel flexibility. This high risk area has a high potential pay-out (50 to 60% energy savings in use areas approximating 50% of the total energy consumption of the country).

Recommended Program

FY 75	FY 76-79 (Total)	Runout	Total
12.9	118.9	119*	250.8*

Costs in millions

*Includes demonstration.

Fuel cells are simple devices which convert chemical energy directly to electrical energy. Wich hydrogen the efficiency is now approximately 60% and may ultimately reach 80%. If the heat loss in converting clean hydrocarbons to hydrogen is taken into account, the present overall efficiency of the electrical power production is about 40% with no environmental pollution.

6. Use of Waste Heat and Fuel

The potential energy and monetary savings through use of otherwise wasted heat are enormous. The energy saved would be equivalent to 1 billion tons of coal or 25,000 tons of uranium each year if, by the year 2000, half the heat required by residences and commercial buildings and half the heat for industrial process heat could all be obtained from the otherwise wasted heat from power production. This heat would have an economic value of $25 billion a year and the power produced in this way a value of $40 billion a year.

The crucial characteristics of the power system that will make this use of waste heat feasible are as follows: (1) The cost of conveying the waste heat from the power conversion system to the place it will be used must be diminished by locating the powerplant near the user of the heat; thus, decentralization of power generation is required. (2) The fluid conveying the waste heat (probably hot water) must be heated to 300 or 400°F and the power system providing this heat must do that without a substantial penalty in its power-producing efficiency. (3) The power conversion system must also have a good power-generating efficiency in order that fuel might be conserved when the demand for heat is low. Overall energy efficiency might reacy 75 or 80%, a level unattainable by any other approach to power generation.

In association with other concerned groups, it will be necessary to carry out systems studies to determine the optimum use of the total energy available. Biological systems can make use of low level heat in the neighborhood of 90°F to 100°F. Thus, for example, the economy of using low level heat in the growing of fish and aquatic plants will be investigated.

Closed-cycle gas turbines and fuel cells have the potential for fulfilling this need. Initially gas turbines should be developed for this service; a power level of perhaps 2 MW would be appropriate. Useful application would be in HUD's program on Integrated Utility Systems.

The technology for fuel-cell systems should simultaneously be advanced in order to improve their cost, life, and efficiency in use of hydrocarbon fuels. After fuel cells become economically viable, their first applications will be in installations too small for gas turbines (perhaps 10 KW); at a later date, they may so improve that they will displace gas turbines in this service.

Exclusive of transportation, clean fuel requirements will exceed 50×10^{15} BTU/year by 1990. Concurrently urban, agricultural and industrial wastes with estimated energy contents of nearly 10×10^{15} BTU/year will be generated and will require disposal. The following technologies for obtaining useful energy from these wastes need investigation: (1) The non-polluting combustion of these wastes as supplemental fuels in power generating systems and (2) pyrolysis and bio-chemical conversion of these wastes to gaseous fuels.

The recommended funding levels are as follows:

	FY 75	Total FY 76-79	Runout	Total
Orderly	13.6	80.7	35.0	129.3
Maximum	21.4	96.2	3.5	121.0
Minimum	8.1	44.1	60.5	112.8

7. Low-Temperature Cycles

Low-temperature Rankine (vapor) cycles using organic fluids or ammonia are suitable for use with geothermal or solar-thermal energy sources and as bottoming cycles for steam powerplants. The technologies for design of power conversion systems rather than three independent, duplicating programs.

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 powerplants is achievable through use of bottoming cycles, the capital cost of the steam powerplant 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 3000 MW to be generated by a single rotating 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:

	FY 75	Total FY 76-79	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.

8. Advanced Concepts

There are a number of advanced energy conversion devices and concepts that have the potential for higher conversion efficiencies over existing systems. These conversion systems which include the Feher (CO_2) Cycle, Thermionics, Thermal Oscillators, Thermogalvanic Cells and Advanced Thermoelectric Materials, should be studied to determine either technical feasibility or suitability for commercial power uses.

The CO_2 cycle system appears to offer efficiencies for central station use in the mid 40% range at 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%.

Other advanced conversion techniques have the potential to increase efficiencies and make more effective the utilization of smaller power conversion systems. The recommended program is for $25 million over a five-year period. Analyses, design studies, and small-scale tests assessing feasibility would all be conducted.

9. Enabling Technology

The Energy Conversion Program needs an undergirding base of enabling technology, specifically, there are requirements for projects to exploit super conductivity to develop the next generation of multi-megawatt electrical converters (motors, generators, and transformers) and to advance materials technology for all energy conversion systems.

The maximum size that generators can be factory produced and shipped to the construction sites is now limited by constraints imposed by our transportation system (bridges, tunnels, etc.). Super conductivity presents the opportunity to build larger, and thus cheaper, machines of a smaller physical size with the added dividend of slightly increased (1/2 - 1%) overall systems efficiency. Industry can be expected to cost-share in the later stages of this area of technology.

There is insufficient engineering and performance data on candidate materials for use in advanced concepts. In order to assure or maximize systems reliability, improve performance, and reduce costs, we must have high-strength minimum-cost materials and the capability to predice their long-term performance characteristics (e.g., mechanical crup, cyclic fatigue, permeability to diffusive species in heat exchange applications). Additionally, new materials and/or coatings must be developed for advanced concepts (e.g., high-temperature gas turbines, MHD) in order to achieve projected goals.

FUNDING

	75	76	77	78	79	75-79	Runout	Total
Accel./ Orderly	8.0	9.0	11.0	14.4	10.0	52.4	60	112.4
Maximum	12.8	14.0	17.4	17.4	17.4	79.0	102	181.0
Minimum	1.8	5.0	7.0	7.0	7.0	27.8	42	69.8