II. STATUS OF TECHNOLOGY

A. COAL GASIFICATION

Coal gasification was a commercial reality in the 1800's and fell from favor with the advent of petroleum and natural gas. Today the Lurgi (German) and Koppers (German) gasifiers are the leaders in commercial units. Efficiency of these units is relatively low (65% to 70%), economics of the process are poor (96¢ to $1.10/10^6$ Btu), operations are limited to only specific non-caking coals, coal feed sizes fall within a narrow range and maximum unit size per reactor is small. Relief from such limitations is the driving force behind the ongoing and future R&D program.

Present activity is primarily directed toward fluidized bed, fixed bed and entrained flow gasifiers. Pilot plants are under construction to convert up to 50 tons of coal per hour. Proven low temperature gas clean up systems removing sulfur and particulate matter are utilized at this time with development proceeding on high temperature gas clean up systems increasing thermal conversion efficiency to be integrated at a future date.

Projections based on R&D results to date indicate thermal plant efficiencies of 80% or better is achievable in the proposed larger size units, economics of 60¢ to 70¢/10^6 Btu, run-of-the-mill cool sizes, and single gasification reactors capable of supplying 1000 MWe fuel requirements.

Small-scale tests have demonstrated the successful marriage of low-Btu gas with the gas turbines/steam combines power cycle at efficiencies in the 40% range.

Two co-funded pilot/demonstration plant contracts are in force between OCR (2/3 cost) and Industry Consortums (1/3 cost) including electric utilities.

2. Barriers to Implementation

Problem areas rather than barriers are well identified and efforts are now underway or are scheduled to resolve them:

High-temperature raw gas clean-up.

Available systems operate in the 400°F or less range and require cooling the raw gas, thereby requiring heat exchange cooling (capital cost) and loss of sensible heat (loss of efficiency). Two approaches are being persued to raise operating temperatures to the 1500°F to 2000°F range.

Turn-down operations ratio

Power generation in utilities requires load following capability of the energy supply system sometimes as much as a 50% or more reduction. Low-Btu gas sources must have this capability since gas, once generated, does not readily lend itself to storage. The R&D program attacks this problem by developing design features and optimizing the number of reactors with operating and capital economics. This problem requires additional study, test and evaluation.

Life of materials

Long-term continuous operation at peak temperatures is yet to be proven at credible sizes. The various planned pilot-size installations will prove or disprove present techniques and R&D findings now underway.

3. Ongoing R&D

Foreign R&D low-Btu coal gasification is practically non-existent. Most effort appears to be in upgrading existing technology into high-Btu gas. In the U.S., 1974 funding is $19 million.

B. GAS TURBINES

Closed-cycle gas turbines with HTGR

The high-power Closed-Cycle Gas Turbine Power System has been under development since 1939. To date there are many plants producing electrical power from 2 MW to 30 MW, some plants having over 100,000 operating hours and future systems with expectations of over 50% efficiency. The operating plants and expected results from larger plants in the 1100 MW range have shown or indicated the following advantages: (1) Load regulation by pressure level variation; (2) High and constant efficiency over wide power-range with simple cycles; (3) Constant temperatures at all loads (low thermal stresses); (4) Turbo-machinery blading working at constant design point and elevated Reynolds numbers; (5) Low pressures combined with High Temperature service; (6) No dimensions of rotating mechanism (valves) at elevated temperature; (7) Small dimensions of rotating machinery and heat exchangers; (8) Low or no cooling water requirement (air cooling); (9) Free choice of working mediums, e.g., helium, nitrogen, carbon dioxide; (10) Possibility of using new materials for components (no oxidation in inert gases); (11) Clean cycle; no problems associated with contaminated atmosphere; (12) Can use a variety of fuels - gas, oil, solid, nuclear; (13) Possibility of light double-wall design; (14) High unit outputs possible; (15) Direct waste heat utilization at elevated temperatures for heating purposes without affecting power cycle efficiency (total energy plants); (16) Limited effects associated with changing density of atmosphere with altitude; (17) Lower weight to power ratio than conventional power systems in the higher outputs.

The reference design parameters proposed based on the status of the technology today would be as follows:

Ambient air temperature	75°F (23.9°C)
Total compressor pressure ratio	2.35
Turbine inlet temperature	1500°F (815°C)
Compressor inlet temperature	95.5°F (35.3°C)
Compressor discharge pressure	1000 psia (69 bars)
Number of compressors	1
Pressure loss ratio	0.075
Recuperator effectiveness	0.89
Turbine isentropic efficiency	91.0%

Compressor isentropic efficiency	88.5%
Turbine disk cooling flow	3.4%
Compressor leakage flow	0.2%
Bearing losses (based on net output)	1.0%
Generator Efficiency	98%
Primary system heat loss	25 MW (t)
Station auxiliary power	5 MW (e)
Station efficiency	35.93%
Net electrical output	1078 MW (e)
Reactor thermal power	3000 MW (t)
Compressor helium flow rate	14,789,400 lb/hr (1863 kg/sec)

Since the net electrical output indicated is 1078 MW, the requirement for the demonstration of a power conversion system of a 275 MW size is mandatory. The technology of turbo machines of this magnitude is within the grasp of turbo-compressor developers. An important construction of a 50 MW(e) closed cycle helium gas turbine, a total energy plant, being built by EVO (Energie-Versorgung Okerhousen) will be gas-fired by a radically new-design, very-compact gas heater. The layout of the plant will allow many operating tests such as regulation of a helium closed-cycle gas turbine using dimensions which would correspond with future sizes in the 275 MW range. This plant is to go into operation in the second half of 1974. There is also a test installation of Jülich which will allow testing of full-size turbine wheels for future plants up to 300 MW as well as testing dents, insulation, and valves to temperatures in 900 to 1000°C region.

This progressing technology will directly support a planned, designed component tested and then assembled as an experimental demonstration plant at the 275 MW net output level in the middle 80's.

Combined cycle using high-temperature open-cycle gas turbines

Past experience with high-temperature open-cycle industrial gas turbines have been limited in size and temperature to less than 80 MW (e) and 1800°F to 2000°F with overall conversion efficiency at about 40% in the combined-cycle application. It is planned that a plant will come into service this year at the 175 MW(e) level 95 MW(e) and 80MW(e) from hot gas exhaust with an estimated efficiency of 41%. The plant is to burn #2 distillate fuel. Technology for gas turbine components needed by high-performance coal-gasification plants do not presently exist.

Open cycle gas turbines are used in a variety of power producing systems, and improvement in their performance in these applications, including reduction in fuel consumption, depends primarily on increased turbine operating temperatures. The results from the 2500°F gas turbine development will undoubtedly find use in some of these applications.

The development of high temperature (2500°F) gas turbine components and systems for open-cycle applications provide a double benefit to electrical power generation. A 2500°F turbine-compressor rotating unit is needed for future high-efficiency gas combined-cycle palnts, which will provide for more effective conversion of coal into clean fuels. The use of this kind of rotating unit with a low-No_x clean-fuel combustor will provide the gas turbine topping cycle for a high-efficiency combined cycle plant which will more effectively utilize the coal-derived clean fuel and other clean fuels such as hydrogen produced by many different means (nuclear and non-nuclear).

Some of the major problem areas that have to be addressed in the development of higher temperature open-cycle gas turbines are in areas of:

Water-cooled turbine blades

Catalytic combuster systems (low emission)

Ceramic turbine blades and coatings

Clean and alternative fuels (coal, hydrogen)

With the application of these principles as far as they are developed, a high-efficiency combined cycle will be demonstrated in the late 1970's indicating a system efficiency of 48% at the 100 MW(e) level.

C. MHD (MAGNETOHYDRODYNAMICS)

Present Status

Three basic categories of MHD electrical power generation systems are currently in various stages of development in the U.S. and throughout the world. These are: open cycle plasma systems; closed cycle liquid metal systems; and closed cycle plasma systems. There is a substantial degree of commonality in the three MHD concepts; however, each system possesses unique characteristics which tend to set it apart. Thus, three parallel research efforts of varying size have been mounted by several countries to develop each system somewhat independent of the other. An excellent summary of the status of R&D on MHD is given in the 1972 report "MHD Electrical Power Generation," Atomic Energy Review 10 (3), IAEA Vienna (1972) 377 pp.

The development of open cycle MHD technology has been conducted mainly in terms of commercial central station application but has also involved special applications, particularly for the powering of weapons and power supplies for special military installations. These developments have progressed to the point where the first pilot plant for central station operation (U-25) has been constructed in the USSR. This plant operates on natural gas and is at present undergoing shakedown. When operated at full design conditions, it will have a power output from its MHD generator of slightly over 20 megawatts.

In the United States, based on the recommendations of the 1969 Office of Science and Technology report entitled, "MHD for Central Station Power Generation: A Plan for Action," the Office of Coal Research of the Department of the Interior started in 1971 a modest program to develop some of the basic aspects of MHD technology needed to prepare the engineering data for later larger scale facilities and integrated plant operations. OCR has established 12 contractors in different areas of MHD. The largest program is being conducted by Avco Corporation. The Avco effort has concentrated on clean fuel although coal combustion can be simulated. In contrast, the other major experimental effort at the UTSI is directed towards the operation of MHD generators directly on the products of coal combustion.

In other programs, Stanford University is investigating basic MHD flow phenomena and boundary layer phenomena, and MIT is looking into the fundamental properties of MHD materials. Major materials work, particularly in coal slag, is geing undertaken by the Bureau of Mines, a three-stage combustor is being set up to study the de-ashing of coal combustion products prior to the generator duct and Westinghouse Research Laboratories are setting up a small facility to study both generator duct materials and the operation of chemical regeneration systems. Other OCR contractors are concerned with system evaluation, component design, and material evaluation.

By far the largest program in open cycle MHD is being conducted in the USSR. At one time, however, substantial programs also existed in the United Kingdom, France and Federal Republic of Germany, but were terminated because of the view prevailing in these countries that electirc power generation needs could be met entirely by nuclear fuel base-load plants and gas-turbine systems for peaking purposes.

In contrast to open cycle concepts, liquid metal and closed cycle systems are not as well developed. These two systems, however, are ideal when used in combination with nuclear sources of heat and R&D efforts are being pursued throughout the world. Liquid metal MHD systems are under study primarily by the USSR, France, Czechoslovakia, Austria, and in the United States by Argonne National Laboratory and the Jet Propulsion Laboratory. Closed cycle plasma research is ongoing in the USSR, common market countries, Japan and in the United States, principally by the General Electric Company. In general both liquid metal and closed cycle concepts have been shown to be technically viable. However, further theoretical and experimental work needs to be conducted before pilot plants can be constructed.

Barriers to Implementation

The construction and start-up in several countries of experimental plants and inplants and installations, including the U-25 pilot plant in the USSR, are the main advance in the field of open cycle MHD. The search for design and engineering solutions that will ensure the reliable operation of all components of MHD power stations during a predetermined service life is characteristic of the work being done with these plants and installations.

Increasing the service life of the basic components of MHD plants is a very important problem for the immediate future. The problem of developing short-operation MHD plants has been virtually solved, but in the case of base-load plants the service life of electrodes, insulating walls and certain other components of the MHD generator and the auxiliary equipment is still relatively short.

In recent years engineering and economic analyses have indicated the possible applications of various types of open-cycle MHD plants in electrical power generation. It has been shown that the relative simplicity of the MHD plant proper makes its use as a peak-load plant a worthwhile economic proposition, while, in conjunction with a steam-turbine plant, MHD results in a substantial increase in efficiency (60%) and is an economically viable means of base-load generation.

The closed-cycle plasma MHD generator itself has proven to be feasible. Sufficient experimental and theoretical background exists to permit extrapolation to large sized with confidence, but no heat source exists.

The development of methods to reduce the major sources of losses, such as instabilities, should be pursued. The technology of long-life ducts has not been thoroughly investigated. However, it seems that no major difficulties should arise, taking into account the much less severe working conditions compared to the open-cycle duct now in an advanced stage of development.

The prospect for introducing closed-cycle plasma MHD plants into electrical power generation depends to a great extent on the development of high-temperature (2000°K) gas-cooled reactors. Many engineering and technological problems remain to be solved but experimental work has been planned to achieve this aim.

Liquid metal MHD plants have also reached the stage where experimental installations are being enlarged. The start-up in the USSR of a closed cycle MHD plant is a substantial achievement.

Like closed cycle plasma MHD plants, liquid metal MHD plants promise to be most successful when used in combination with nuclear sources of heat. However, the requirements with regard to the preheat temperature of the coolant (liquid metal) in the nuclear reactor are less extreme in this case, a temperature in the range 1200°F being quite sufficient.

At present, therefore, open cycle MHD plants are the closest to being introduced into electrical power generation. Already there are grounds for considering it possible to build pilot peak-load and base-load open cycle MHD plants capable of good engineering and economic performance.

Overall the main barrier is lack of sufficient funding to maintain R&D at levels warranted by the advantages projected for these systems.

Ongoing R&D

The largest program in MHD is being conducted in the Soviet Union and is estimated to exceed an annual funding rate of $50 million. In contrast, the USA, principally under OCR sponsorship, has open cycle work ongoing which amounts to approximately $7.8 million for FY 1974. Closed cycle R&D funded primarily through AEC and DoD is estimated to be about $.6 million for FY 1974.

D. Potassium Topping Cycle

The technology for the potassium Rankine system was developed during the 1960's as part of the nuclear space power program conducted by NASA, AEC and the Air Force. As a result of this effort, hundreds of thousands of hours of beneficial testing have been accumulated on components for use with potassium. For example, the AEC successfully built and operated pumps, boilers, condensers, and a small 10 kW vapor turbine. NASA constructed a "breadboard" power plant facility to test potassium turbines that comprised, in addition to the turbine, a fossil-fired furnace/boiler of 3 MW heat input capacity, an 8-inch vapor throttle valve, a condenser and a boiler-feed pump. The two largest potassium turbines ever built were tested at 1500°F in this facility, each for more than 5000 hours. The results of the work conducted by these government agencies have been to demonstrate the technical feasibility of the potassium Rankine cycle.

The system was built entirely of stainless steel and was operated in air. The boiler was fired with natural gas and boiled potassium at 1500 - 1550°F. The rotor of the potassium turbine was supported by oil-lubricated bearings and drove a dynamometer that was operated in air; an argon-buffer shaft seal kept air from entering the potassium loop and potassium from mixing with the lubricant. An oxygen - control device continually monitored the potassium stream for contamination by small amounts of oxygen and continually purfied a small portion of the potassium stream by removing trace amounts of oxygen; the problems of oxygen control for the sodium stream in the LMFBR program are very similar to those for potassium, and the results of this very large program should substantially benefit the both potassium - topping system and the liquid metal MHD system.

The technology which has been developed for the potassium space power system can readily be applied to the development of a topping plant of high efficiency for stationary power. No new "breakthroughs" in technology are required and much of the potassium component and system testing was conducted at the operating conditions appropriate to the topping plant. The effort proposed herein is, therefore, aimed directly at proving the advantages of building commercial-scale (1000 MW) plants by construction of a pilot plant by 1979 and a demonstration plant by 1983.

NASA and OCR have begun a joint program to develop the potassium topping plant for use with both coal in a fluidized bed and fuels derived from coal. A preliminary design and economic assessment of a commercial-scale plant and a conceptual design of a pilot plant will be prepared by an industrial team by early FY 1975. In addition, the AEC's Oak Ridge National Laboratory is building a module of a pressurized furnace/potassium boiler.

E. Fuel Cells

The fuel cell was discovered by Sir William Grove in 1839, but found its first practical use in the United States Space Program, where Fuel Cells were used to furnish electrical power in the Apollo and Gemini missions because of their favorable power to weight ratio. The fuel cell is a simple device which resembles in a great many respects the familiar lead-acid storage battery used in cars. It differs from the storage battery in that the electrodes of the fuel cell do not change with use. The fuel (e.g., H_2) is converted into water at the electrode by electrochemical oxidation, producing electricity. The fuel cell works as long as fuel is supplied to the fuel electrode.

Fuel cells are presently under development for advanced space, underwater, and other government special purpose applications. The technology required to satisfy the government application does not lend itself to direct transfer to the civilian sector where economics are of paramount importance.

The major effort to develop commercialized fuel cells in the U. S. A. is by Pratt and Whitney Aircraft (PWA) using hydrogen-air fuel cells. There are matrix cells using phosphoric acid as the electrolyte. PWA has one major program with the gas industry (TARGET) to provide fuel cells as part of a total energy system for apartments, commercial use, and possibly individual residences. A second major program is with the electric utility companies to develop dispersed fuel cell generator stations. These two programs are probably being supported with a total of 15 million/year.

In the TARGET program a number of 12 KW demonstrater power plants are presently in operation. The hydrogen is furnished by reforming natural gas on site.

In the dispersed fuel cell generator program, the present projected cost of the PWA power plant on a production basis is $350/KW with an operating life of 16,000 hours. Substantial progress has been made in the last five years; specific material cost has been reduce 10-fold, and operating life increased 5-fold. A specific cost of $185/KW and a 40,000 hour operating life would establish the fuel cell as an economic electric generator. Rate of progress has been limited by funding.

Another major commercial fuel cell program with private funding is a joint effort between France's Alsthom and Jersey Enterprises, Inc., which is a subsidiary of Standard Oil of New Jersey (EXXON). This 5 year $10 million effort is aimed primarily at developing methanol-fueled fuel cell systems for small power applications in the 5-25 KW range. Recently this effort was extended to embrace the dispersed fuel cell generator application. It is reported that methyl alcohol can be produced at a favorably low price of about $1.00/00^6 BTU. It can also be made extremely pure, which is important for fuel cell use.

Englehard Minerals and Chemicals Corporation is offering commercial hydrogen-air fuel cells using phosphoric acid matrix cells in various sizes. The hydrogen is obtained by cracking ammonia. This cell has over a year of demonstrated life.

A number of U. S. and foreign organizations including GE. Westinghouse, Allis-Chalmers, Union Carbide, British Railways, Brown-Boveri and others have also been involved in fuel cell activities over the past decade.

Fuel cells are low-voltage direct-current devices and thus this characteristic must be designed around. At present platinum is the electro-catalyst of choice but it is expensive and scarce. Fuel cell life also is less than desirable, the flexibility of fuel cell use would be improved if a wide variety of fuels were available for direct. use.

F. Use of Waste Heat and Fuel

(1) Waste - Heat utilization

One of the highest energy demands in the country is in the area that can be handled by small decentralized energy producing systems. A nominal size that has wide application is in the area of 1 to 3 MW(e) for small industry) shopping centers, total utilities systems, and institutional (hospital-school-etc) and the like. There are at least 600 total energy systems designed or operating in the United States using off-the-shelf technology. With the development of innovative technologies and the application- of the most successful of these advanced ideas, much improved and more efficient and reliable management and use of waste heat can be realized.

Many areas of energy conversion, heating, ventilation, air conditioning waste water treatment, potable wate treatment, control of systems, solid waste processing, distribution systems, and fuel sources are in operation and in many stages of product improvement.

There is a requirement that the most applicable of these be advanced and used in a appropiate application. Some energy converties lend their relves to waste heat usage better than others.

(2) Use of waste fuels

Methods of energy recovery and conversion from waste fuels include: (1) Combustion of wastes in incinerators with heat recovery to generate steam, (2) combustion of waste fuels in utility, industrial or commercial boilers, (3) combustion of waste fuels in fluidized bed combustor with energy recovery by steam or gas turbine, (4) conversion of wastes by pyrolysis into solid, liquid, or gaseous fuels for use in supplementing natural fuels, and (5) bio-chemical conversion of wastes to liquid (alcohol) fual for use in supplementing natural fuels.

Incineration of urban wastes with heat recovery is little used in the

U. S. A small number of U. S. municipal incinerators generate steam for on-site use or for sale and some smaller commercial and institutional incinerators use waste heat boilers for central heating and other uses. But these incinerators generally pollute the atmosphere and are socially offensive.

These wastes can be burned without pollution and with good energy recovery if 80 or 90 percent of the combustion heat comes from a conventional fuel. The use of shredded municipal refuse as an auxiliary fuel to provide 10-15 percent of the energy input in a utility boiler is currently being demonstrated under joint sponsorship of the federal Environmental Protection Agency, the City of St. Louis and the Union Electric Co. This program will determine the costs and techniques of processing and suspension firing shredded municipal refuse in a pulverized coal firing utility boiler. This demonstration is scheduled for completion in late 1974. Preliminary studies indicate that the combined net costs of electrical generation and waste disposal can be reduced by firing solid waste as an auxiliary fuel. No adverse environmental effects are expected. Further work is needed to develop technolgoy for processing, storage and transportation of urban wastes and for firing it in oil-burning utility boilers and in smaller industrial and commercial boilers.

Fluidized-bed combustors are under development for use in advanced power plants and waste-disposal plants. The waste-disposal plant, which is currently under development at pilot-plant scale, operates on shredded municipal wastes and generates electricity by use of a gas turbine. Fossil fuels are used only for plant startup. Major development problems include erosion, corrosion and fouling in the gas turbine by the particle-laden combustion gases. It is anticipated that development of high-temperature gas cleaning equipment for the plant will be completed in late 1975. Development of this fluidized-bed for gas turbines should be completed through full-scale demonstration since it is a new process and would probably not receive other support until proven.

Fluidized-bed combustors with chemically active beds are currently being developed to provide a more cost-effective and environmentally acceptable method of producing power from high-sulfur coal. Demonstration of the use of auxiliary waste fuels in these combustors should be conducted during the overall development program which is scheduled for completion in 1979.

Fuels to supplement natural fossil fuels can be made by the conversion of waste fuels through pyrolysis (gasification) and reforming techniques. While these processes are not economically or thermally as efficient as direct combustion, clean fuels can be generated for use elsewhere. The Bureau of Mines estimates a possible production of 170 million barrels of oil per year from organic wastes. The conversion of municipal waste, forestry waste and agriculture waste to oil and gaseous fuels is currently being studied at laboratory and small pilot-plant scale. Numerous laboratory experiments and several pilot plants have demonstrated the feasibility of generating fuels from various wastes. A 200 tpd pyrolysis plant which will operate on municipal wastes is being designed and is scheduled to complete demonstration tests in 1976. About 40% of the dry organics in the incoming waste stream will be converted to an oil with a heating value of 10,600 BTU/lb. Economics of the process depend to a large degree upon credits obtained through recovery of aluminum, glass and ferrous metals contained in the input municipal wastes. Other plants are also under development by private industry. The waste-fuel pyrolysis techniques are designed primarily for waste disposal and have not been optimized for energy recovery. Without government support, implementation of this technology to generate clean fuels for non-central power-station use will be delayed until 1985 or later.

Promising biochemical techniques for the generation of alcohol fuels from municipal refuse and sewage sludge or from agricultural wastes have

have been demonstrated in laboratory experiments. Development of these processes are currently hampered by R & D fund limitations.

G. LOW - TEMPERATURE CYCLES

The thermodynamic properties of many of the potential working fluids are readily available and widely known; examples are ammonia, the freons, and various Dowtheoms, already in commercial use for refrigeration and the supply of process heat. The AEC and NASA have supported R & D on organic-Rankine cycles at Aerojet and Sundstrand for about a decade, although these systems were of only 3-50kw. Adaptation of this existing technology to higher powers is required.

H. ADVANCED CONCEPTS

The feasibility of some components of a CO_2 (Feher) cycle has been demonstrated. A 20 HP supercritical CO_2 closed loop was operated in 1960 and a 60 HP turbopump was successfully tested in 1971. These tests indicated component advantages in efficiency, size, weight, and first cost over steam turbines which the cycle would replace in electric power generating central station systems.

The technical uncertainties to the CO_2 system include:

1. The design, size, materials and cost of primary and secondary heat exchangers
2. The lifetime of turbine bearings and high-pressure shaft seals
3. The economic evaluation of the whole conversion systems (a design study) by architect-engineering firm.

The DOI is funding a 0.5 million dollar effort in FY 1974 for analytical studies and experimental work on subscale components.

Virtually all research in Thermionic Power Conversion up to the present time (AEC/NASA) has been directed toward the development of high-temperature, reliable thermionic converters for space power applications. In life tests an electrically heated converter has exhibited constant performance at 2900° F for over five years. Individual converters have demonstrated conversion efficiencies of about 16% at temperatures of 3100° F. A 10 kilowatt thermionic nuclear reactor is under construction in France, and a 10 kilowatt thermionic reactor has been in operation in the USSR since 1970. Advanced types of thermionic converters have been demonstrated in the laboratory which are potentially capable of efficient operation at temperatures low enough for use as a topping cycle in an advanced fossil fuel decentralized power plant.

The technical uncertainties to the thermionic topping cycle include:

1. The improved performance of thermionic converters at lower temperatures (1800-2000° F).
2. Materials and heat transfer technology to allow operation in corrosive environments.

The AEC is funding a 0.70 million dollar effort in FY 1974 on work directed toward improving the efficiency and lifetime of the basic thermionic diode at low temperature (2000° F).

A thermogalvanic energy converter is a high-temperature (1000° C) hybrid between a regenerative fuel cell and a thermoelectric device (could be considered a liquid thermoelectric device or a galvanic concentration cell). A laboratory device utilizing sodium as the working fluid and a solid-state electrolyte-(alumina) has been built and demonstrated a conversion efficiency of about 30%.

The technical uncertainties to improved performance include:

1. The lack of available solid electrolytes to conduct ions other than sodium
2. The need for suitable electrodes and corrosion-resistant cell materials.

Efforts to date have been limited to about two years of a one-man effort.

Thermal oscillators are machines in which freely oscillating positive-displacement elements (free pistons) periodically subject a working fluid (helium or hydrogen) to a thermodynamic cycle (Stirling type), producing a net work output. Laboratory models of this device have demonstrated a cycle-indicated thermal efficiency of 60% at 1400° F. A 30 watt linear alternator-free piston Stirling engine has achieved 10% overall efficiency at 800° C.

Technical uncertainties to the thermal oscillator engine are:

1. The power output limitations of this type engine when combined with linear electric power generators.
2. The size of heat-transfer surfaces required for engines in the kilowatt range of power.
3. The performance of the engine gas seals.

Free-piston Stirling engines have been under investigation for the past few years at universities in England, Canada, and the United States. Some limited industrial investigations are being conducted and a Stirling free-piston engine, implantable nuclear heart-assist system, is being developed under the sponsorship of the National Heart and Lung Institute.

New high-temperature selenium-composition thermoelectric materials are under development with a potential thermocouple efficiency of 16% in the temperature interval of 1800°/400° F. An all-selenide thermocouple has operated over 3000 hours with stable performance in the temperature interval 1500°/400° F.

The technical uncertainties to the advanced thermoelectric materials are:

1. The need to optimize the N-leg material to match the P-leg material performance in the thermocouple.
2. The need to demonstrate stable thermoelectric couple performance at hot-junction temperature of 1800° F.

The AEC is supporting this work for space systems application and the FY 1974 funding is 0.4 million dollars.

I. ENABLING TECHNOLOGY

(1) Superconducting Electrical Machinery

The technology of electrical machinery - meters, generators, and transformers - have reached their limit of development by conventional means. The maximum size of generators which may be factory built and shipped to the power plant site is now limited by their physical size which may be handled by our transportation systems (railroad bridges and tunnels, e.g.). The principal advantages of superconducting machinery would be a marked reduction in weight and size which in larger units could achieve economics of 15-20% in cost per kilowatt capacity. An added benefit would be in increase in conversion efficiency up to 1% in the larger units. The recommended program is directed toward the development of the next generation of multimegawatt generators, motors, and transformers for energy conversion, including materials, refrigeration technology and manufacturing. Industry would be intimately involved, including cost sharing in the later stages.

Westinghouse and MIT have built .5 MVA and 2 MVA generators, respectively. The English have completed a 3,250 HP superconducting motor and are building a one MW motor-generator set for naval propulsion. The French, Japanese, and Germans also have active programs in this area.

There are no technological barriers anticipated in this sub-program; however, considerable engineering R&D will be required. The availability of higher-transition-temperature superconducting wire would result in lower refrigeration and development costs and further increase the overall system efficiency.

(2) Advanced Materials Technology

The first generation of MHD generators, gas tubines, and other conversion systems will, of necessity, be constructed using currently available materials at the limit of the state of the art. The next generation will require advanced materials or materials which are insufficiently industrial in terms of the environment or the conditions under which they will be expected to perform. For example, micro-impurities in helium (H_2 & CO) can have catastopic effects on gas turbine blades and other components even at moderate temperatures. The mechanisms and rates of an attack are poorly understood and alternate materials must be found to insure long life and reliability for advanced-HTGR applications.

For MHD the mechanisms of seed and slag attack in insulator,electodes, and duct materials must be investigaged. Slag must be characterized. For many of the existing candicates materials the required data back of mechanical, electrical, and chemical properties does not exist and must be acquired to optomize their use, project their long-term performance, and permit meaningful component testing.

For heat exchanges high strenth, creep and cyclic-fatigue resistant materials are required which also are corrosion resistant, have low permability to diffusive, contamining species, and are thermally conductive. Heat exchanges are common to all conversion systems; yet each imposes its own set of materials requirements. Expensive and time-consuming failures in the past have shown that this is a neglected area of technology.

FUNDING

	75	76	77	78	79	75-79
____/orderly	8	9	11	144	10	52.4
Maximum	12.8	14.0	17.4	17.4	17.4	79.0
Minimum	1.8	5.0	7.0	7.0	7.0	27.8