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POTENTIAL RESEARCH PROGRAMS IN WASTE ENERGY UTILIZATION

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ABSTRACT

A successful solution to the energy problem will depend, to a great degree, on the optimized use of converted energy forms and on the maximum utilization of by-product or waste energy and materials. Industrial waste energy in many cases can be utilized as energy sources for combustion air preheating, process heating, and thermodynamic engine cycles. Reducing and/or eliminating waste energy will increase energy efficiency and will lessen environmental problems throughout the chain of extracting, processing and supplying energy (i.e., waste energy utilization is a means of pollution control). This paper discusses potential research areas of interest to the Power Technology and Conservation Branch (PTCB) of EPA's Industrial Environmental Research Laboratory in Cincinnati, Ohio (IERL-Ci). The PTCB waste energy utilization program will assess the relative economic/environmental effects of using waste energy and assure that control technology is developed to the extent required. Emphasis will be on the industrial area but other waste-energy utilization or pursuits could be included except as related to the conventional electric utility industry. Our sister IERL at Research Triangle Park, N.C. has responsibility for the conventional utility industry. However, longer range advanced concepts related to utilities will be emphasized, by IERL-Ci for example, the integration of utilities with industries for combined production of electricity and space and process heating to minimize waste heat rejection.

INTRODUCTION

There is great concern that the United States will experience grave difficulties in acquiring adequate supplies of energy necessary to sustain economic growth throughout this decade and well into the next. The energy problem is exceedingly complex and involves many factors. For instance, the increasing concern for environmental quality has delayed the exploitation of nuclear energy and restricted the utilization of coal. A further constraint is the desire to conserve finite and depletable domestic supplies of gas, oil, coal, and uranium. A successful solution to the energy problem will depend, to a great degree, on the maximum utilization of byproducts or waste energy materials. The developments in this area should be assessed by EPA to make certain that environmentally sound alternatives are considered and that EPA ORD will be in a position to advise EPA regulatory and enforcement programs. This paper will cover potential research areas of interest to the Power Technology and Conservation Branch (PTCB) of EPA's Industrial Environmental Research Laboratory in Cincinnati (IERL-Ci). These are primarily the industrial and longer range applications of waste energy utilization. The IERL at Research Triangle Park, N.C. has responsibility for the conventional utility industry.

In general, the sources of pollution in utility or industry sectors are from combustion and/or industrial processes. The control of these pollutants consists of several alternatives, such as physical and/or chemical scrubbers. Unfortunately, most of these controls are energy intensive and need a great deal of capital investment for installation and maintenance. Furthermore, some of these controls are not highly efficient. This difficulty and the projected shortage of environmentally clean fossil fuels have provided an incentive to reduce pollutants by saving energy or by utilizing recoverable energy effectively. Several studies of waste heat utilization and its related areas have been conducted by various agencies, such as ERDA, NSF, and FEA [1,2,3]. Their results have shown that significant amounts of energy can be saved and pollutants can be reduced. Their results also warrant that further research in this subject area to assess environmental impacts, qualitatively and quantitatively, is urgent and cannot be neglected.

It is envisioned that the results of the PTCB program will provide data for the Office of Air Quality Planning and Standards and Effluent Guidelines Staff to develop standards and regulations, and will assist federal, state and local energy and environmental agencies and industrial planners in developing methods and technologies for the most environmentally sound recovery and use of waste energy.

PROPOSED RESEARCH PROGRAM

Several potential alternatives capable of reaching our program goals are described in the following. It is considered that programs 1 and 2 are the first priority, 3 and 4 second priority, and 5 and 6 third priority. This is a ranking by a priority system of 1 through 4 which has been used for overall Power Technology and Conservation Branch priorities.

1. Environmental Assessment of Industrial Waste Energy Utilization

The objectives of this program are to determine (1) whether energy recovery is practical from various waste energy streams to be identified as a result of our contract study entitled "Waste Energy Inventory for Major Energy-Intensive Industries," (2) what recovery methods might be employed to obtain maximum thermal efficiency, (3) what environmental impacts would be caused by the implementation of these recovery methods, and (4) what percentage of pollutant reduction and energy savings should be achievable.

Any discussion of the waste energy generated by industry and discharged into the environment must begin with a discussion of the energy consumption by industries, because these are the sources of waste energy. Waste energy generation from a particular industry should be roughly proportional to that industry's energy consumption. Those industries, which consume the most, would be expected to contribute the most waste energy generation, and thus would be expected to have more potential for waste energy recovery.

Waste energy generated from electric power production is usually considered as a point source. An extensive study has been conducted both in quality and quantity, and a great deal of data on its recovery and utilization have been documented. However, because the needs and levels of process heat in industry are so numerous and varied, industrial waste energy is generated in a much more diffused manner from a wider variety of sources than thermal power plants. It may suffice to say that almost every chemical and/or physical change in industrial processes involves some degree of change in process heat application and waste heat generation, thus affecting waste energy recovery methods. Comparable data in these areas have not been fully developed. ERDA, presently, has a project to study industrial process energy consumption. EPA is expecting to complete a waste energy inventory for industries by the end of 1977. This proposed research program of waste energy utilization is a continuation of that EPA project. Emphasis will be placed on the environmental effects from the application of various waste energy recovery methods.

In determination of the practicability of waste energy recovery, there are several important factors which need to be considered:

(1) Quantity of waste energy and method of rejection;

(2) Quality of waste energy: for example, two processes may have the same amount of waste energy rejected to cooling water which reaches the same temperature, but if energy from one source is rejected with a higher temperature difference than the other, that energy has more thermodynamic availability or capacity for doing work and hence is more valuable.

(3) Degree of fluctuation in industrial device operation: some devices operate continuously with very steady conditions. Petroleum process heaters and glass furnaces are such devices. Other devices are operated with batch feeding over a set operating cycle. Metal melting furnaces are of this type. Still other devices are tied to an industrial process that is of an inherently fluctuating nature. Cement kilns and paper-mill boilers have constantly fluctuating operation dependent on the feed material properties and on process control adjustment.

Because of the above reasons, the alternative waste energy management methods and the potential beneficial uses for each waste energy source would be quite different, and thus the environmental impacts and/or pollution controls needed might be quite different as well.

While some study results [5,6] of waste heat utilization on some specific industries are available, there is very little available, to our knowledge, on quantities of potential waste energy recovery from entire specific industries, and even less on environmental impacts of the waste energy after being utilized. The lack of the required environmental data and the critical need for it in examining alternative waste energy management methods make this proposed research program vitally important. It is only through this study that environmentally sound systems can be developed, and that our desired objectives to reduce pollutants and save energy simultaneously can be reached.

It is well recognized that a significant amount of waste energy from industrial sectors is rejected to surroundings, causing thermal pollution to our environment. For example, approximately 866 X 10^{12} Btu/yr. from petroleum refineries [3] is rejected to surroundings through condenser cooling water. It was found that over 80 percent of waste energy is rejected in the 300-600° F temperature range. From a thermodynamic point of view, a large portion of this heat is recoverable and can be converted to mechanical work by means of proper cycles. ERDA [7] estimated that almost 13 quads, which is about 7 percent of total national needs, can be saved in the year 2000, if industrial energy efficiency is improved and waste heat is utilized. There are several approaches which would be applicable to waste energy recovery. These approaches include the following:

(1) Combustion Air Preheating:

Combustion air preheating is used extensively on larger industrial boilers. However, many industrial devices do not have air preheat because, in the past, fuels were cheap and the cost to install preheat was more than the fuel savings achievable. This method is believed to have the widest possible application. For example, a preliminary analysis of the waste gas energy recovery potential for an aluminum melting furnace is significant. The furnace has a very high stack temperature, 1225°K. Stack energy content is about 52 percent of the fuel input energy of 7 Mw. Installation of a combustion air preheater at 50 percent heat exchanger effectiveness could recover 43 percent of the stack gas waste energy. This would result in about a 23 percent reduction in fuel consumption. However, since preheating combustion air will increase flame temperature to some extent, the added NO_x formation needs to be identified [8]. It is believed that there are many other industries, similar to the above example, and that a significant amount of waste energy can be recovered by this means. The purpose of a study of this concept would be to classify the industries in which the combustion air preheating concept can be applied, to assess the energy-saving potential, and to assess the environmental impacts from each specific industry.

(2) Process Heat Utilization:

Many industrial processes make use of steam generated by heat from waste streams or transfer heat directly to the process. However, because fuel was cheap in the past, the full potential for utilization of waste energy in the process may not have been realized. One of the potential applications in this area is waste heat utilization from interstate pipeline pumping stations. Considerable horsepower in diesel and combustion turbine pumping engines is required to operate the nation's network of pipelines. Most pumping stations are located on pipelines within the industrial triangle lying between Pittsburgh, Chicago, and Birmingham. Significant amount of waste energy is generated by these engines. It is technically feasible to use this waste energy to generate steam for industrial use. For example, if one chemical plant producing 80 X 10^4 Kg/day of ethylene dichloride utilizes this steam supply, it could entirely eliminate operation of one of the three boilers in the plant and operate the second at only one-third of its present output. Therefore, the potential of transferring waste energy to process needs should be investigated to the extent possible. Again, the environmental effects by implementing this process heat utilization need to be studied, because it might produce different environmental effects from different process heat utilization.

(3) Thermodynamic Heat Engine Cycle:

Generally speaking, waste energy recovery by the first and second approach should be higher in efficiency than this third one. However, when waste energy cannot be used for combustion air preheating or be used in the process, it may be practical to apply the waste energy recovered to a thermodynamic engine cycle for generation of electrical power. Approximately 30 percent of waste energy can be converted into electrical energy by this scheme. Although several thermodynamic engine cycles can be applied to recover waste energy, a Rankine cycle with organic working fluid seems to be the most promising one. However, this is subject to further study to ensure that this Rankine cycle will produce the maximum efficiency without causing any harmful environmental effects.

A summary of waste energy management can be found from Figure 1. Major forms of waste energy having potential use as heat sources are: (a) hot stack gases from furnaces and boilers, and (b) hot water from cooling of processes directly through jackets or through heat exchangers, cooling towers and condensers. The figure shows three potential waste energy recovery approaches and two ultimate receiving media, either air or water.

To show the idea of waste energy recovery and utilization, an example of a thermodynamic engine cycle was given in this paper. Figures 2 and 3 show the flow chart and temperature-entropy diagram of the Rankine cycle with normal pentane as the working fluid. The working fluid in this cycle is heated to its vaporization temperature then to its superheated state at constant pressure process (line 2-3-4-5-6). This dry saturated working fluid is then introduced into a turbine and expands isentropically to low pressure to produce mechanical work (line 6-7). The turbine effluent is cooled and condensed in a constant pressure process (line 7-8-1). The condensed fluid is then recycled by means of a pump (line 1-2).

The heat source for the cycle is from waste heat of industrial processes. For example, heat rejected from condensing or cooling of process steam can be used to heat and vaporize the Rankine cycle fluid. Hot combustion gas from fuel-fired heater stacks can be a heat source for superheating of the Rankine cycle fluid in its vapor phase. With this particular working fluid, the turbine effluent vapor is still in a superheated state as indicated on Figure 2 at state point 7. The cycle efficiency can be improved by recovering part of this energy (line 7-8) to heat the feed liquid going to the boiler (line 2-3).

Assume that this Rankine cycle, using waste energy from a petrochemical plant as heat sources, has turbine conditions of 410°F, 250 psia and condenser of 14.7 psia with sink temperature of 97°F, and working fluid of normal pentane with a flow of 1,000,000 pounds per hour. Figure 2 and n-pentane property tables were used to obtain the necessary thermodynamic properties. It was calculated that the waste energy from this petrochemical plant can produce 145 x 10^6 kwh/yr. of electricity, save 1413 x 10^6 Btu/yr. of input fuel, reduce 303 ton/yr., 175 ton/yr., and 25 ton/yr., of SO_2, NO_x, and particulate pollutants respectively. This pollutant reduction calculation was based on the assumption that the emission level is equal to the level set by New Source Performance Standards (NSPS). Also, 505 x 10^9 Btu/yr. of thermal pollution can be eliminated.

The Rankine cycle low level waste heat recovery system offers an attractive means of reducing pollutants and conserving energy simultaneously. This potential application may be found in the energy-intensive industries, such as chemical, petrochemical, petroleum, ferrous and non-ferrous metals, paper and pulp, etc. Other low temperature sources, such as geothermal and solar energy, may also prove to be applicable.

Although waste heat utilization will offer so many advantages, the environmental aspects of industrial Rankine bottoming cycles have not been fully documented and need to be assessed by EPA as these systems are developed so that controls will be inherent in their design. In most cases, thermal pollution will be reduced but added environmental risks may result. Examples include the effects of Rankine cycle working fluid, which is usually a volatile organic compound, on heat exchangers. Will there be any volatile compound fugitive emissions in normal operation? What would be the environmental hazards of chemical reaction from the flue gas and organic working fluid in case of leaks? What would be the environmental problems because of working fluid disposals? These are only a few questions which should be asked. Answers are needed.

2. Industrial Waste Hydrocarbon Recovery and Utilization

Most of the activities of pollution control agencies have been directed toward control of principal emission sources, such as SO_2, NO_x, and particulates, with little attention thus far to those smaller sources, such as sources emitting hydrocarbons (HC), resulting from various industrial processes, particularly from chemical plants and petroleum refineries. Because of certain small sources which when lumped together constitute a major source which was estimated at 47 billion pounds emitted in 1970 [9] the potential emission problems of these sources should be a matter of increasing concern.

The afterburner system to control HC emission is one of the earliest techniques developed and is probably still the most nearly universally used control method being used to control not only volatile organics, but also odors and particulate hydrocarbon emissions. The afterburner functions by incinerating a waste gas stream in a direct flame produced by the combustion of an auxiliary fuel, mostly natural gases. The need of auxiliary fuel for this approach has been dictated by two factors: (1) waste gas streams generally have low heating values, and (2) organic vapors are frequently diluted with air to well below lower combustion limits in order to satisfy fire and safety requirements. A schematic diagram of this thermal incineration is shown on Figure 4.

From energy conservation and pollution control points of view, the current afterburner system to control HC is a most uneconomical and inefficient approach. Some of the apparent drawbacks to the use of afterburners are readily identified as the following.

(1) In order to have better combustion efficiency, the entire waste gas stream must be heated to approximately 1400°F, regardless of the concentration of the combustible material. Since the concentration of organics in most waste streams is usually low, this necessarily means that a large portion of the fuel used is for a totally unproductive purpose, i.e., heating air. In a typical installation, natural gas consumption can easily reach 3 percent of the waste gas stream volume.

(2) The addition of natural gas to help combustion of HC means a double waste of our natural resources, i.e., natural gas and combustible HC. It was estimated that approximately 0.9 trillion scf of natural gas [9] annually, which is about 3.7 percent of the entire national natural gas need, is consumed for nationwide afterburner systems.

(3) Because HC could contain toxic elements, it would be very hazardous to human health, if there is any malfunction or incomplete combustion in the afterburner systems.

(4) It is highly possible that the afterburner system itself will present some safety problems. These include the explosion potential, toxic elements released from the system, formation of smoke, noise, and the emission of air pollutants during flaring.

Until recently, the low cost and ready availability of natural gas encouraged the use of afterburners. Unfortunately, this situation has now changed. The current and projected shortages suggest that natural gas supplies are or may be curtailed in some areas of the country, and the installation of new gas-consuming equipment thus may become increasingly restricted. In addition, the priority systems that are being developed for gas distribution may not consider air pollution control a significant factor. In other words, industrial area or statewide curtailments of natural gas may not take into account air quality control needs. As a result, we would begin considering the possibility of compliance problems that directly result from reduced natural gas availability or energy conservation and pollution control.

One of the potential approaches to save the energy is to recover heat from flue gas if HC are burned. Recovery methods include heat exchange between hot flue gas and incoming cool HC stream, and the use of the heat in other processing or heating loads, such as in generating steam for plant or process heating, for power generation, etc. Further research and development is needed to develop environmentally sound technologies to recover and utilize HC.

3. Detailed Assessment of Electric Utility-Industrial Integrated Use Concepts

Our preliminary contract study entitled "Environmental, Economic, and Conservation Aspects of Integrated Energy Use Applications" with Georgia Institute of Technology, has found that this integrated energy use application will substantially reduce environmental pollution and save energy. Tentative conclusions have shown that the integrated energy use application appears to make technical sense because no new technology is needed, has the potential to reduce national energy consumption by 15 percent or more, and thus to reduce pollutant emissions considerably, and provides lower cost than the conventional separate systems. Since this contract is a conceptual study oriented program, further study is needed to ensure that appropriate environmental data are available for technology development. Therefore, we are proposing a continuation of this program for a detailed assessment of the most promising approach of integrated energy use indicated in the Georgia Tech. study. It appears now that emphasis should be placed on the combination of in-plant power generation and process heat production due to the foreseeable near term implementation.

It has long been recognized that electricity and steam can be generated together in the same plant with a higher thermal efficiency than they can be generated separately. The reason for this is that in a central station of a fossil fuel-fired steam power plant, about one-third of the energy of the fuel is converted into electricity and two-thirds escapes in the form of thermal discharges. Some of this thermal discharge consists of flue gases from the combustion process entering the atmosphere at temperatures of 300-600°F. Most of the discharge results from the condensation of steam and the subsequent rejection of this heat to bodies of water or the atmosphere at temperatures of 70-100°F. Industry, when it generates steam and electricity together, increases the temperature of the reject heat from the power cycle to useful levels which are, in fact, sufficient to provide the steam required in processes. The result is that industrial process steam serves as the sink from the power cycle, thus decreasing thermal discharge substantially. The effective thermal efficiency of the industrial power plant generating steam and electricity together is about 60-75 percent, whereas a central station steam power plant is today about 35 percent efficiency.

As a result of the large amounts of steam used in industrial processes (about 7 percent of all the energy used in the U.S.), considerable amounts of power can then be generated by this technique with half to two-thirds of the fuel currently used in central station plants.

In-plant generation of electricity in industry potentially has numerous national advantages. The most important of these are to conserve energy, reduce pollution as a result of lower fuel consumption, and increase reliability and security by having a multi-source electrical generation system rather than a smaller number of larger systems. The thermodynamic potential for in-plant generation depends strongly on the types of systems. In most industries, there is good potential for combined production of electricity and steam by utilizing a steam and/or gas turbine topping cycle for higher efficiency.

There are several combinations, such as steam turbine topping, gas turbine topping, combined gas and steam turbine cycle, and diesel engine topping system, to accomplish the in-plant power generation purposes. The equivalent efficiency for the power generated is about 70 percent compared to 35 percent of simple unit. The efficiency is high as a consequence of all the rejected heat from the cycle in the turbine exhaust being used for the process. The only real system losses are boiler combustion gas losses, generator losses, and a portion of turbine losses which do not remain in the fluid streams. The heat rate also presumes that full exhaust stream enthalpy is recovered as usable heat. It was estimated that the maximum thermodynamic potential for in-plant power generation in 1974 is the fuel equivalent of about 550,000 bbl oil/day, 150,000 bbl oil/day, and 2,200,000 bbl oil/day for steam turbine, gas turbine and diesel engine topping systems, respectively [3]. Schematic diagrams of a steam turbine topping and a combined gas and steam turbine cycles are shown on Figures 5 and 6, respectively. Referring to Ref. 3 of in-plant power generation from petroleum refinery industries, a rough estimate of energy savings and pollutant reduction is shown in Table 1. Again, the pollutant reduction estimate was based on the New Source Performance Standard (NSPS) level.

As indicated in the above estimates, increased in-plant generation can lead to substantial overall energy savings and will lead to reduce environmental effects. However, because of differences in types of fuel and types of fuel burning equipment and location of fuel burning to generate electricity, the environmental effects of this approach have not been fully evaluated. It may be expected that in addition to conventional pollutants, SO_2, NO_x, and particulates, there may also be more exotic species, such as fluorides, chlorides, etc., originating from combustion emissions. Environmental impacts and problems with removing potentially harmful species are magnified by the close proximity of source and receptor. Emissions which have traditionally been considered on a point source basis may now require treatment as a quasi-area source because of increased numbers of point sources. Also, the fuel composition in these applications could be highly variable. This may require a new generation of control techniques.

4. Stack Gas Energy Extraction Vs. Plume Formation

Another potential area for energy recovery is the heat released via stacks related to combustion. Fossil-fuel electric power plants, industrial incinerators, and individual industrial processes, such as steel making and calcining of minerals, constitute major candidates for evaluation of stack waste heat recovery and reuse.

It was found that the stack waste heat from the petroleum industry is approximately 67 x 10^{12} Btu/yr. at temperatures of 300-600°F and 261 x 10^{12} Btu/yr. at 600-1000°F [3]. It was calculated that if proper organic Rankine cycles are applied to this waste heat, 177 x 10^9 kwh/yr. of electrical power [3] can be produced and significant amounts of pollutants can be reduced because of less fuel consumed. However, there is an upper limit of energy extraction from stack gas because of conditions required for proper plume formation out of the chimney. Some potential problems can readily be identified as the following.

1. The influence of heat recovery on plume buoyancy reduction and hence, on plume rise and the subsequent ground level ambient concentration, of SO_2, NO_x, and particulates is significant.

2. The effects of heat recovery are not only on stack gas temperature but also on the humidity in the plume. There is a possibility that heat recovery will cause the acid dew point to be reached within the plume and thus permit the direct emission of acid gases of sulfur and nitrogen. This, would affect ambient sulfate and nitrate concentrations and cause corrosion to materials.

3. Item 2 can also affect the frequency of occurrence of visible plumes because of enhanced condensation. Although not strictly a pollution problem as far as health effects are concerned, visible steam plumes are not aesthetic and can be considered as a type of insult to the environment.

The information on this subject is very limited and has received little attention in the literature. From environmental and energy conservation points of view, further study is essential in order to have maximum heat extraction from stack gas without causing any environmental effects. Emphasis should be placed on: (1) thermodynamic property effect on plume formation, (2) environmental impact from plume redistribution, (3) possible material corrosion, (4) potential of applying aerodynamic chimney control devices (this technique was used in Europe) to help plume distribution.

5. Environmental Assessment of Thermal Energy Storage

Commercial thermal energy storage (TES) systems will be accepted first by industry, according to a recent General Electric Company [11] study. TES systems include: storage well (injection of warm water into the ground for storage); sensible heat storage, such as solar ponds, fuel oil/granite mixtures, and heat transfer fluids; latent heat storage, such as salts and salt eutectics, including fluorides; and thermochemical heat storage in reversible chemical reactions, such as:

$SO_3 \rightleftarrows SO_2 + 1/2O_2$, $CH_4 + H_2O \rightleftarrows CO + 3H_2$, $CaO + H_2O \rightleftarrows Ca(OH)_2$, $NH_4HSO_4 \rightleftarrows$

$NH_3 + H_2O + SO_3$, and ammoniated paired salt decompositions.

GE has conducted extensive research on the heat storage well concept [11] and has found that this concept is technically feasible. Some of their conclusions are excerpted as the following: (1) it can reduce annual energy consumption of the U. S. by 10-15 percent; (2) preliminary analysis indicates that three-fourths of the energy stored can be recovered even after 90 to 180 days of storage in a large well; and (3) a combustion gas turbine system with heat recovery and storage shows a cost savings of about 25 percent and energy savings of over 35 percent, compared to systems with no storage.

One of the possible applications of this storage well concept is to the EPA integrated energy use program. Basically, the EPA program is to match heat and power load well enough, so that heat storage is not necessary. However, if, for some reason, the heat production is more than the need for industrial processes, use of storage wells would increase the flexibility of integrated energy systems.

According to GE, the U. S. Geological Service has budgeted $100K per year for fiscal years 1977-80, and ERDA has budgeted $200K per year for the same years to continue the research efforts. However, the environmental effects of this area have never been studied before. Some of the potential environmental problems might be similar to the problems encountered in geothermal energy applications. Injection technology is needed and its environmental viability must be proven. Also when the storage well discharges hot water to the surface, some pollutant species from underground might cause pollution to the above ground environment.

Since other agencies have committed funds for technology development for storage wells, it is EPA's obligation to assess the environmental impacts and to develop pollution controls, if needed, so that pollution control can keep pace with storage well technology development.

Other TES seems relatively unimportant for the near term compared to storage well. However, environmental effects of the other concepts need to be studied at an appropriate time. Some of their environmental problems include the effects of molten fluoride container rupture. Will there be fluoride fugitive emissions in normal operation? What would be the environmental hazards of a reversible chemical reaction storage using SO_3? What will the environmental impact be for solar ponds? These are only a few of the questions which should be asked and answered.

6. Environmental Assessment of Advanced Power Transmission Vs. Decentralization of Power Generation

The use of energy in the form of electric power was 26 percent of the total annual energy consumption in the U. S. at the end of 1974 [12] and is estimated to increase to 50 percent in the year 2000. The current average power transmission distance from a power plant to end users is about 80 miles, with the longest distance about 800 miles, and the trend is to increase the average distance, to some extent, according to the data from the Electric Power Research Institute (EPRI). The EPRI data also show that the power transmission efficiency is approximately 93 percent, and the cost for transmission facilities is about 40 percent of the entire power plant investment. Based on these data, power transmission will consume about 2.7×10^{15} Btu or 1.5 percent of the national energy need, which is about 180×10^{15} Btu [13] in the year 2000.

To reduce the energy consumption for power transmission line losses, technologies under development include two major items: decentralization of power generation, such as in-plant power generation and/or integrated energy use application, and advanced transmission line technology, such as ultra-high voltage transmission lines (both AC and DC) and superconducting (cryogenic) transmission lines. The question is which technology will provide more energy savings and less unwanted pollutants--decentralization of power generation or advanced transmission line technology. Comparable data are unavailable at the present time. It is important to initiate a program for a comprehensive study of advantages and disadvantages of these two major technologies from various points of view. As far as the environmental effects are concerned, in general, decentralized power generation should be similar in environmental effects to conventional power systems. However, advanced transmission line technology seems to have more hazardous environmental effects. For example, both occupational and general population groups will be exposed to the potential hazards associated with this technology. Workers involved in production, construction and maintenance activities will be exposed to hazardous insulator materials (for example, sulfur hexafluoride and PCB substitutes) and cryogenic fluids. Workers and local population may be exposed to strong electric fields, increased ozone levels and audible noise. The health effects of concern include adverse changes in biological processes caused by strong electric fields, toxic effects of sulfur hexa-fluoride or other new insulator materials, as well as possible induction of shock irritability and increased pulmonary dysfunction.

Nevertheless, advanced transmission line technology could provide significant energy savings, compared to decentralization of power generation. Therefore, it is essential to initiate a program to study their differences, particularly from the environmental point of view.

Priority Rating of Research Areas

The above areas were rated by a rating system shown on Table 2. In this rating system, potential energy saving and pollution reduction carry the same major rating weight with 40 percent for each of them. The cost effectiveness and immediateness are assigned 10 percent each. This rating weight reflects the major thrust of our program - energy conservation and pollution reduction. Both of these factors can be a measure of environmental significance. Energy conservation will reduce pollution throughout the energy production and distribution system while the reason for emphasizing the pollution problems of the specific concept are obvious. The factors of cost effectiveness and immediateness is intended to weigh the priorities somewhat to the more practical and soon to be commercialized technologies. For example, if two programs have the same amount of rating from energy conservation and pollution reduction aspects, then the cost effectiveness and immediateness should be able to provide enough leverage to decide which program is more valuable for EPA.

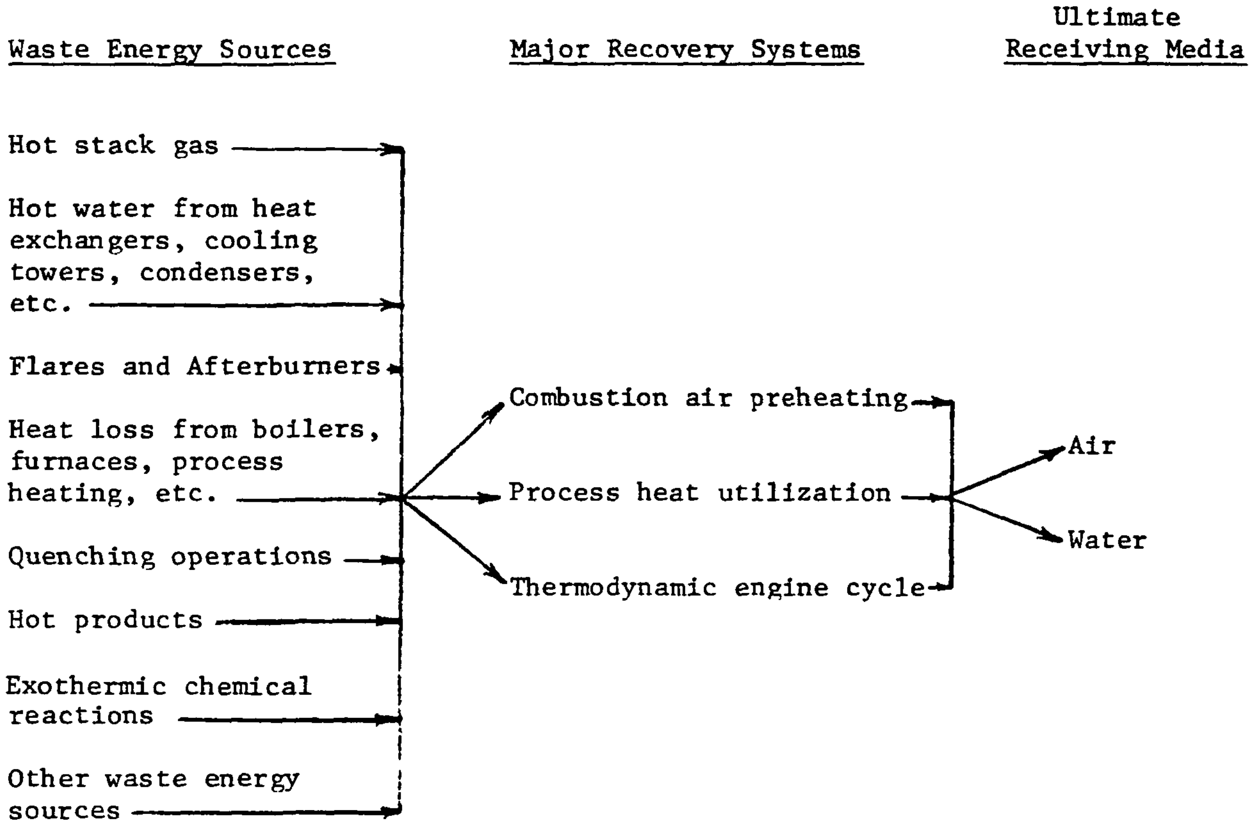
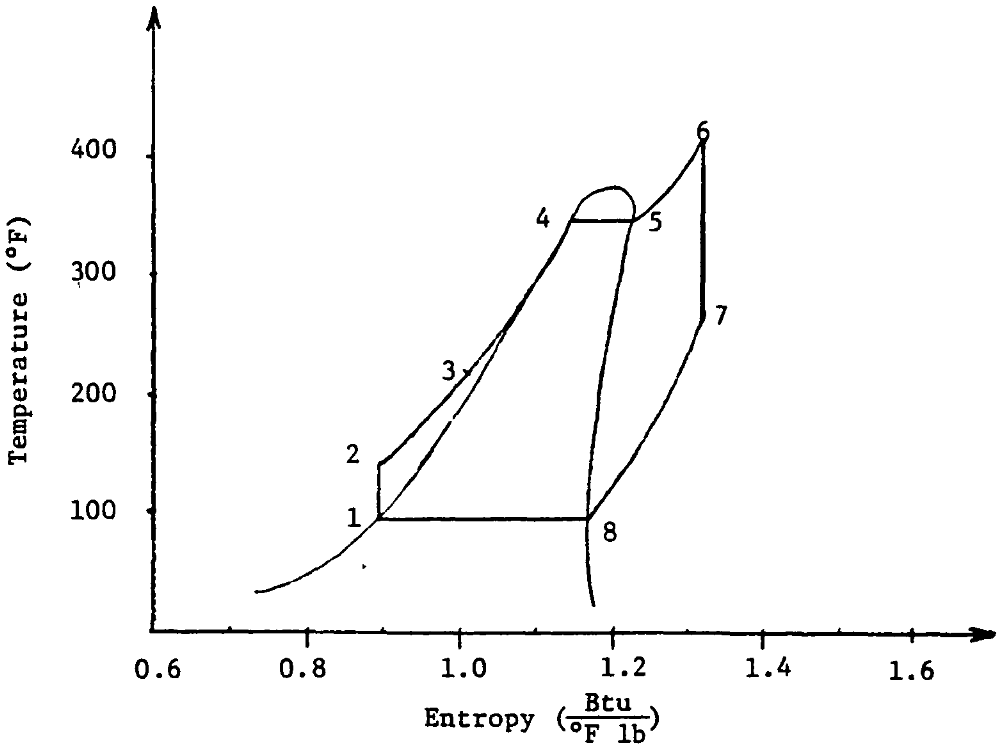


Figure 1. Waste Energy Management



2-3-4-5-6: Constant pressure heat transfer from waste heat stream.

6-7: Isentropic expansion in the turbine to produce mechanical work.

7-8-1: Constant pressure cooling process.

1-2: Isentropic pumping process.

Figure 2. Organic Rankine Cycle (n-Pentane Working Fluid)

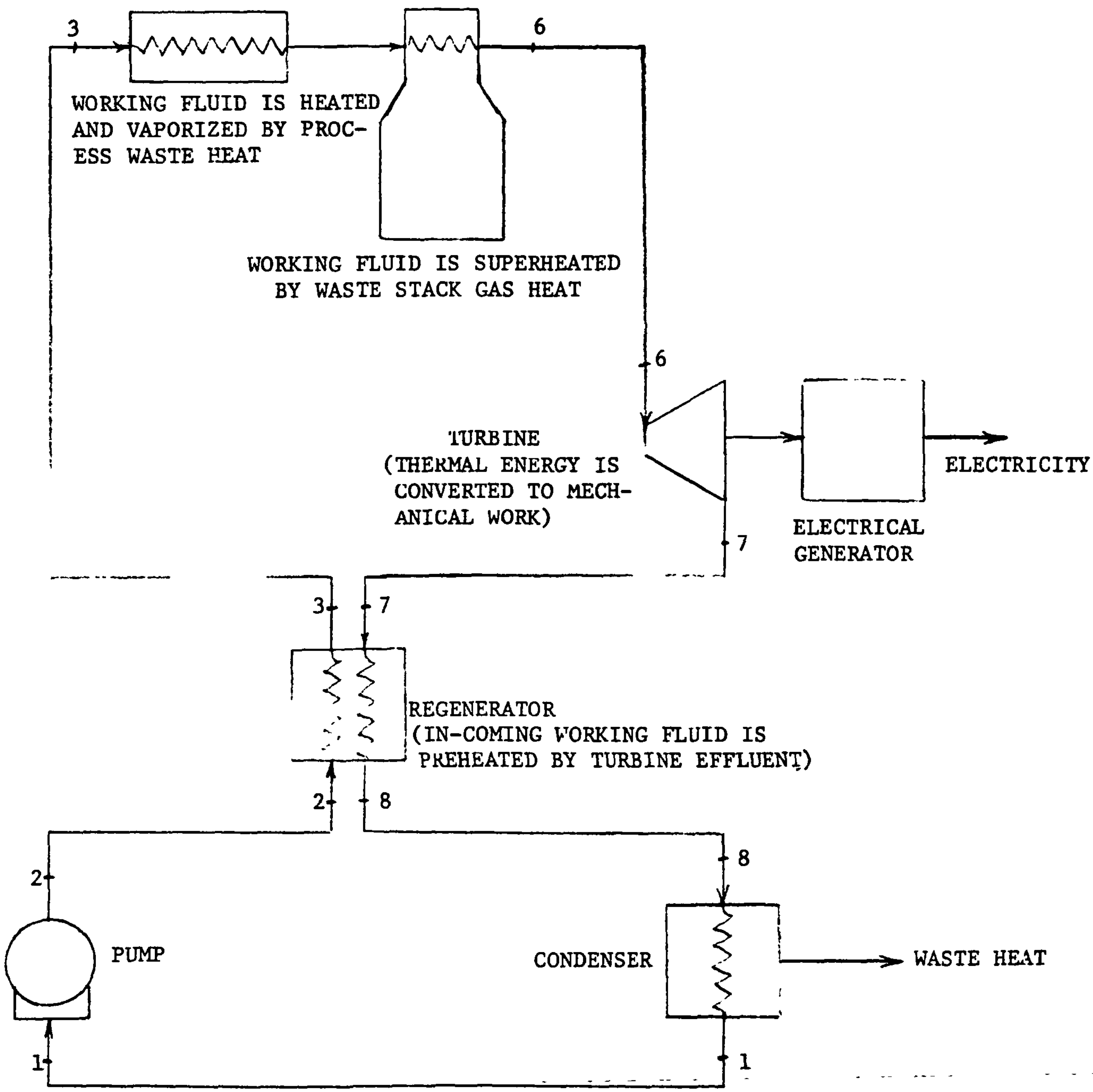


Figure 3. Organic Rankine Cycle System (Station Numbers Correspond to the Numbers on Figure 2)

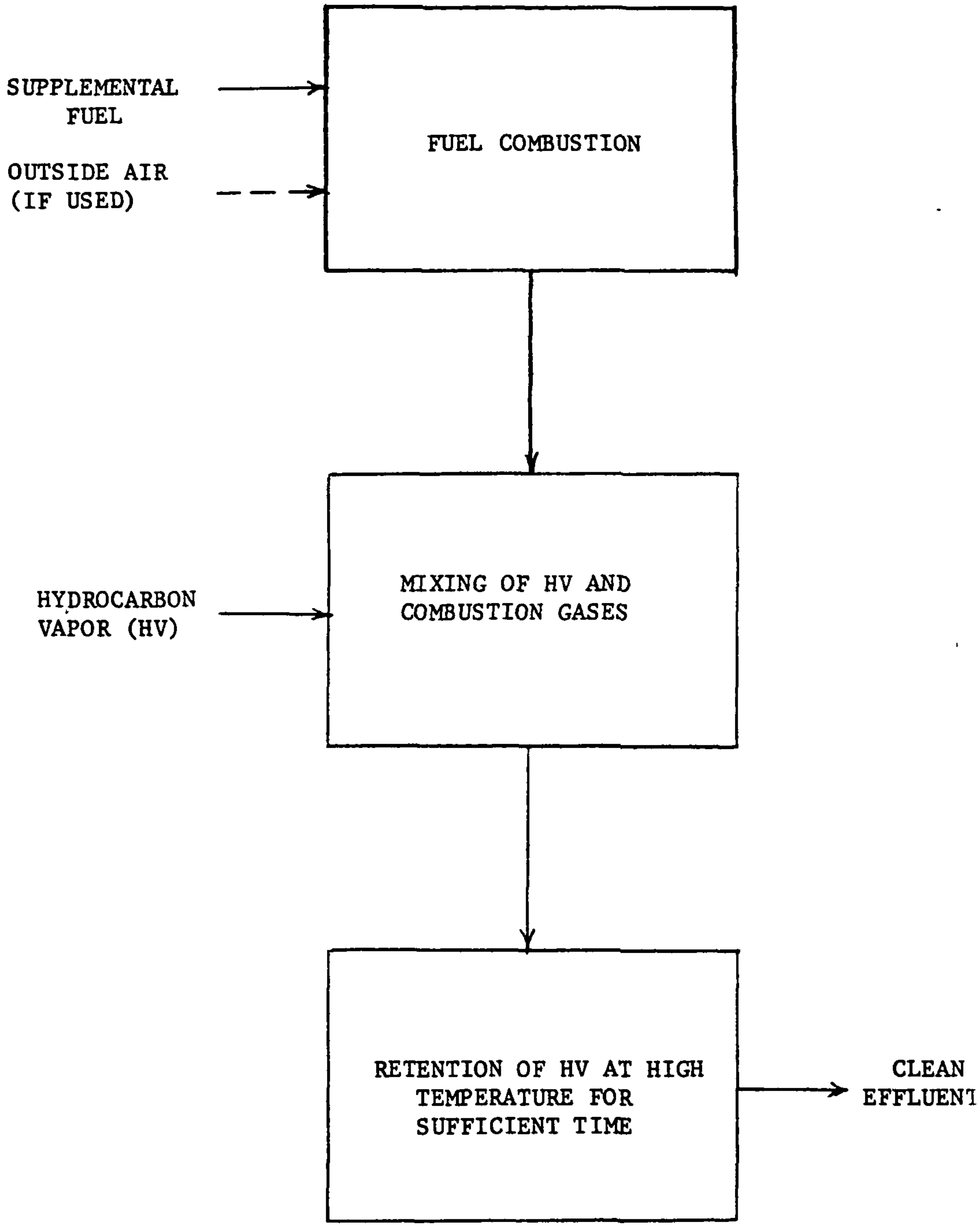


Figure 4. Steps Required for Successful HV Incineration

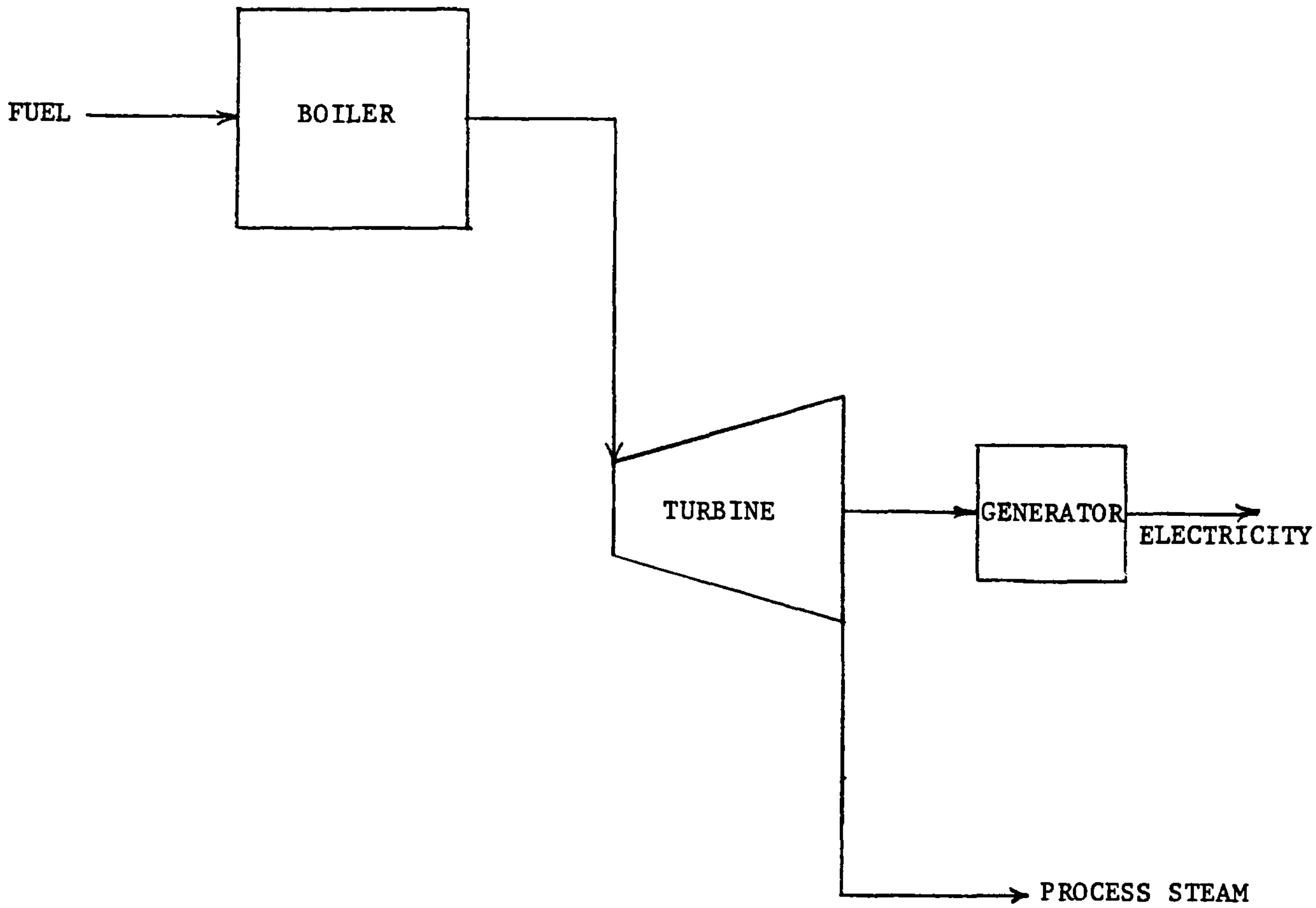


Figure 5. Steam Turbine Topping Cycle

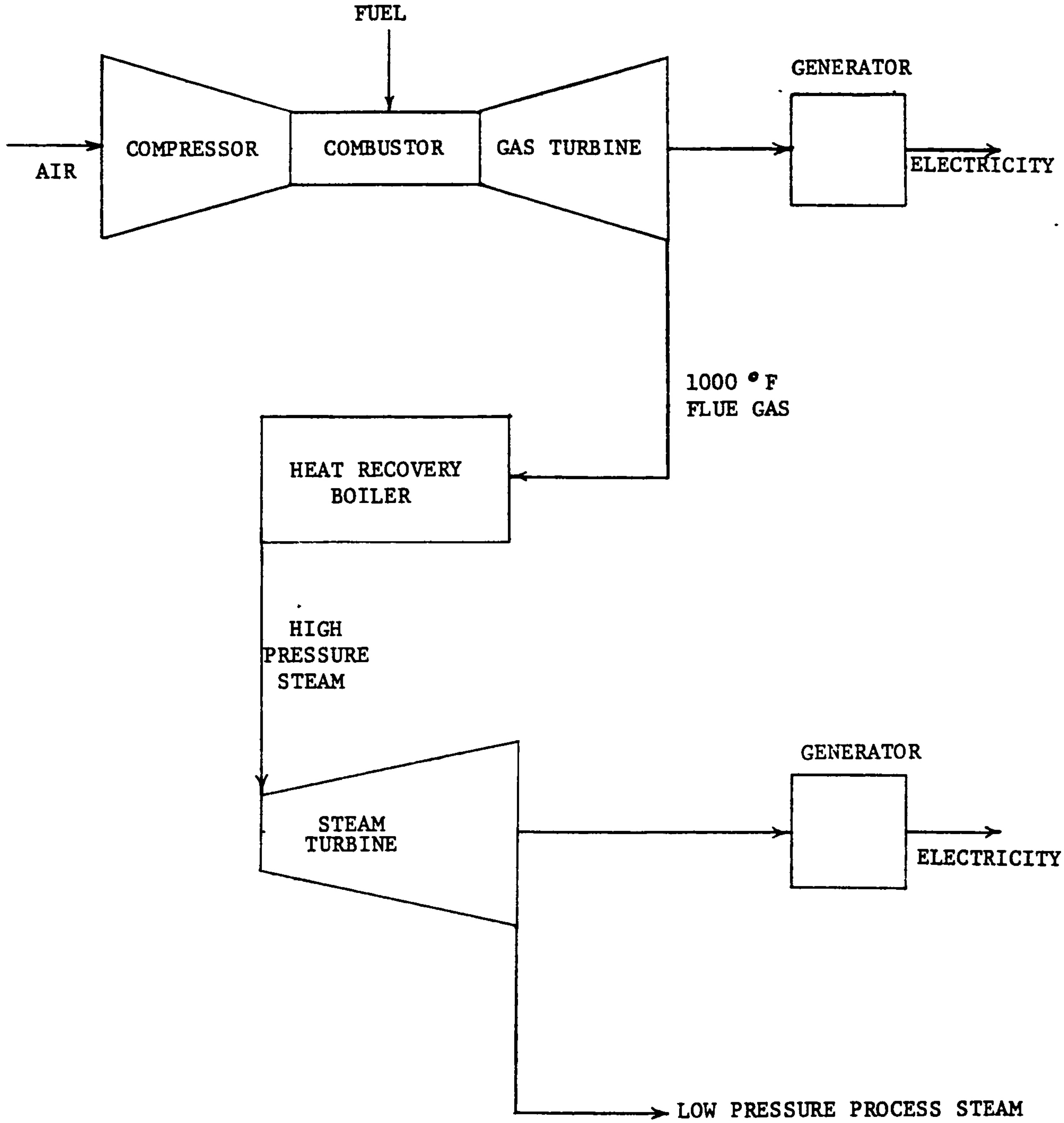


Figure 6. Combined Gas and Steam Turbine Topping Cycle

TABLE 1

ENERGY SAVING AND POLLUTANT REDUCTION
FROM IN-PLANT POWER GENERATION
IN PETROLEUM REFINING INDUSTRY

	Steam Turbine	Gas Turbine	Diesel Engine
Power generation by topping of process steam and process heat (10^9 kwh/yr.)	5	196	397
Energy saved from fuel input to central power plant (10^{12} Btu/yr.)	183	706	1,431
Pollutant reduction (ton/yr.):			
• SO_2	109,800	423,600	812,400
• NO_x	64,050	247,100	473,900
• Particulates	9,150	35,300	67,700

TABLE 2. PRIORITY RATING ON PROPOSED WASTE HEAT UTILIZATION PROGRAMS

	Relative Weighting	Waste Energy Utilization	Waste Hydrocarbon Utilization	Integrated Use Application	Stack Gas Energy Extraction Vs. Plume	Thermal Energy Storage	Power Transmission Vs. Decentralization
1. Energy Conservation Potential							
a. Incentive for energy conservation, e.g., large energy user or user of fuel in short supply.	20	20	20	20	20	20	20
b. Potential for energy saving or increase in efficiency.	10	10	7	10	7	10	7
c. Potential pollution control energy savings.	10	10	10	10	7	7	7
2. Pollution Reduction Potential							
a. Seriousness of pollution problems in project area.	20	15	15	10	10	10	10
b. Potential for developing required control technology designed to remove desired pollutants to operate reliably, and to discharge acceptable effluents--or for reducing pollution by the major process change.	10	10	10	7	10	10	7
c. Breadth of applicability to other areas.	10	10	10	10	10	5	7
3. Cost Effectiveness, Profit Potential, Etc.	10	10	10	10	10	7	7
4. Immediateness of Potential Impact of the Technology	10	10	10	10	10	5	5
TOTAL	100	95	92	87	84	74	70
COMMENTS		← First Priority	→	← Second Priority	→	← Third Priority	→

REFERENCES

1. "An Assessment of Industrial Energy Options Based on Coal and Nuclear Systems," ORNL for ERDA contract, ORNL-4995, July 1975.

2. "High Efficiency Decentralized Electrical Power Generation Utilizing Diesel Engines Coupled with Organic Working Fluid Rankine Cycle Engines Operating on Diesel Reject Heat," Thermo Electron for NSF contract, TE 4186-27-75, November 1974.

3. "A Study of In-plant Electric Power Generation in the Chemical, Petroleum Refining and Paper and Pulp Industries," Thermo Electron for EPA contract, Report No. TE 5429-97-76.

4. "Patterns of Energy Consumption in the United States," Stanford Research Institute, 1972.

5. "Proper Waste Heat Utilization Reduces Air Pollution and Saves Energy," Ken J. Suoboda and H. J. Klooster, presented at the 69th Annual Meeting of APCA, June 27 - July 1, 1976.

6. "Sulfuric Acid Plant Rankine Cycle Waste Heat Recovery," G. P. Lewis, etc., presented at the 11th Intersociety Energy Conversion Engineering Conference Proceedings, Volume II, September 12-17, 1976.

7. "A National Plan for Energy Research, Development and Demonstration," ERDA-48, Volume 1 of 2, June 1975.

8. A private conversation with KVB.

9. "Afterburner System Study," Shell Development Company, NTIS, PB-215 560, August 1972.

10. "Flare Systems Study," EPA 600/2-76-079, March 1976.

11. "Role of the Heat Storage Well in Future, U. S. Energy Systems," General Electric Company, GE 76 TMP-27, October 1976.

12. "Energy Fact Book--1976," Tetra Tech, Inc., for Navy, Feburary 1976.

13. "The 1975 Energy Management Guidebook," McGraw Hill, Inc., 1975.