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# BENEFITS OF SOLAR/FOSSIL HYBRID GAS TURBINE SYSTEMS





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# Benefits of Solar/Fossil Hybrid Gas Turbine Systems

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ABSTRACT

The potential benefits of solar/fossil hybrid gas turbine power systems were assessed. Both retrofit and new systems were considered from the aspects of; cost of electricity, fuel conservation, operational mode, technology requirements, and fuels flexibility. Hybrid retrofit (repowering) of existing combustion (simple Brayton cycle) turbines can provide near-term fuel savings and solar experience, while new and advanced recuperated or combined cycle systems may be an attractive fuel saving and economically competitive vehicle to transition from today's gas and oil-fired powerplants to other more abundant fuels.

## 1.0 Introduction

A national program to demonstrate the achievement of large-scale conversion of solar energy to electricity is currently underway. A major goal of this program is to develop and demonstrate the technology required to establish technical feasibility and indicate economic viability of solar electric power systems.

In considering the integration of solar thermal conversion powerplants into an electrical power grid, the issues of capacity and energy displacement must be assessed. The capability of solar powerplants to displace conventional generating capacity will be impacted by outages due to reduced solar radiation because of cloud cover or during non-sunlight hours. In addition, this impact will vary for different operating modes such as baseload, intermediate, or peaking. The effect of solar insolation outage can be reduced or compensated for by providing an energy storage subsystem to maintain a continuity of useful output. Although no systems suitable for large-scale energy storage have yet been fabricated, the U. S. Department of Energy is sponsoring studies to integrate thermal energy storage subsystems with solar powerplants.

An alternate concept to compensate for solar insolation outage is to combine solar and fossil-fueled subsystems in a common powerplant. This is referred to as a hybrid solar thermal system. This type of system utilizes both solar and fossil fuel energy to provide thermal input to a single energy conversion subsystem at a powerplant site. Hybrid systems are applicable to existing conventional powerplants (retrofit) or to new or advanced powerplant concepts. The energy conversion subsystem used in a hybrid system may operate on any thermodynamic power cycle. The fossil fuel used may be gas, oil, coal or coal-derived synthetic. The solar energy collection subsystem may be flat plate, parabolic trough or dish, heliostat/tower, or any combination of these. In addition, the solar and fossil fuel energy may be combined in either of two operational modes. In the first mode, the energy conversion subsystem operates solely on solar energy during period of high solar insolation and fossil fuel is used as "storage" only to be used during periods of solar outage. The second, and potentially more versatile, mode of hybrid system operation utilizes fossil fuel energy to augment the solar energy source to provide a temperature increase of the energy conversion cycle working fluid. This mode can still provide a "storage" capability as in the first mode, for operation during periods of solar outage.

A previous study by the author (1) investigated the technical and economic feasibility of a wide variety of candidate solar/fossil hybrid power systems. The matrix of systems considered is shown in figure 1. The criteria used to identify attractive solar/fossil hybrid options included; cost of electricity, fossil fuel savings, mode of operation, and technology development requirements. Application of these criteria to the matrix of candidate systems showed that gas turbine powerplants (sinple, recuperated, and combined cycles) were the most attractive hybrid options. This paper was prepared to present the benefits for

[1]H. S. Bloomfield, J. E. Calogeras; Technical and Economic Feasibility Study of Solar/Fossil Hybrid Power Systems; NASA TM-73820; December 1977.

these powerplants and to examine the potential of hybrids as a transition vehicle from present day to future combustion turbine technology.

## 2.0 Benefits

The benefits of solar/fossil hybrid gas turbine systems will be discussed in terms of the criteria previously presented and discussed in the Introduction. An additional criterion--fuels flexibility--will also be discussed from the aspect of how future transition from petroleum to coal based fossil fuels can enhance the viability of solar/fossil systems.

## 2.1 Cost of Electricity

On an energy cost basis, the gas turbine hybrid system, in both retrofit and new applications, was found to be the most attractive option. This is illustrated in figure 2 which compares solar thermal and conventional powerplant energy costs at a constant fuel cost. The input parameters used to generate these results are shown in Table 1.

The benefit that accrues from low energy cost is competitiveness with intermediate and baseload conventional utility powerplants. Both retrofit and new hybrid gas turbine systems can be used to provide early introduction of solar collector hardware in competitive energy cost powerplants. In addition, the assumption of any fuel cost escalation rate will tend to increase the competitive nature of hybrid systems since conventional powerplants require more fossil fuel for equal electrical energy output.



## 2.2 Fossil Fuel Conservation

In terms of fossil fuel conservation, gas turbine hybrid powerplants were shown to provide significant benefits. For example, the potential fuel savings for a state-of-the-art solar hybrid simple open cycle gas turbine powerplant can be obtained from figure 3. This type of combustion turbine powerplant is in widespread use by the utility industry to provide peaking service. Furthermore, nonelectrical generation versions of these turbines are also used extensively by the gas transmission industry for pumping service. Solar energy input to the air working fluid is assumed to be provided by a conventional metal tube heat exchanger (receiver) operating at an average temperature of $760^{\circ}C$ ($1400^{\circ}F$). For a typical turbine inlet temperature of $982^{\circ}C$ ($1800^{\circ}F$) and a solar input of about 60 percent, a fuel savings of

6500 Btu/kWe hr is obtained. For an average fuel cost of \$2.84/GJ (\$3.00/M Btu) during operation, and a 3000 hour annual solar duration and operating time, the annual solar fuel savings is approximately \$59/kWe.

## 2.3 Operational Mode

Selection of the hybrid system mode of operation was shown to be an important element of the gas turbine hybrid powerplant[1]. Two solar/fossil hybrid system modes were identified and are illustrated in figure 4. The simplest mode is where fossil fuel is used solely to extend hybrid system operation beyond the sun hours. Thus, fossil fuel is equivalent to an extended duration energy storage subsystem that provides equal (or better) system performance during periods of low insolation or no sun. This parallel energy input mode is designated as solar or fossil operation.

Another operational mode, designated as solar and fossil operation is where fossil fuel is used to not only extend operation beyond the sun hours but, in addition, can provide an enthalpy increase to the system working fluid. Fossil fuel in this series energy input mode, can therefore augment solar energy input to provide an increase in energy conversion efficiency and power output by increasing peak cycle temperature levels. And, more importantly, the additional power output derived from fossil fuel augment is obtained at substantially improved fuel "utilization". For example, a hybrid combustion turbine employing a fossil fuel augment of solar receiver output temperature from 760$^{o}$C (1400$^{o}$F) to a 1093$^{o}$C (2000$^{o}$F) turbine inlet will burn fossil fuel at an incremental efficiency approaching 50 percent.

Some typical schematic design configurations illustrating the locations of series and parallel energy inputs are shown in figure 5.

## 2.4 Technology Requirements



The choice of operational mode has an important effect on technology development requirements. For example, a parallel arrangement of solar or fossil energy inputs will require the development of a solar heat exchanger (receiver) that can meet modern gas turbine inlet temperature requirements of 982$^{o}$C (1800$^{o}$F) and higher. In addition, the current trend towards improving gas turbine efficiencies will drive turbine inlet temperatures to even higher levels. This could result in an expensive and lengthy technology effort to develop higher temperature capability solar receivers for parallel (solar <u>or</u> fossil) hybrid gas turbine operation. For the case of series (solar <u>and</u> fossil) hybrid gas turbine operation, the technology required would be similar to current development efforts to improve methods for combustor cooling of advanced conventional (fossil-fired) machinery. This is considered to be a significantly less expensive and shorter duration development than that required for parallel operation. Therefore, the benefit of a series of mode of gas turbine hybrid operation, wherein fossil fuel is used to augment solar energy input temperature to utilize more efficient machinery, is an early introduction of a viable solar application with only minor technology advancements required.

## 2.5 Fuels Flexibility

A potentially important future benefit of hybrid gas turbines results from multifuel capability. This capability, if fully developed, can enable a fossil augmented solar hybrid gas turbine system to serve as an attractive, fuel-saving vehicle over the time period required to transition from scarce fossil fuels to alternate energy sources. This transition could be accomplished in a series of steps that would parallel those recently proposed by the U. S. Department of Energy, Division of Power Systems (2). The proposed program will emphasize the development of critical technologies in support of advanced stationary gas turbine engines that progress from today's clean (gas and distillate oil) fuels, to near-term heavy residual oils, and eventually to coal

[2] Industry Briefing by U.S. Department of Energy, Division of Power Systems, March 2, 1978.

derived fuels. Major near-term emphasis is placed on technology improvements for directly-fired heat cycles, such as gas turbines, to facilitate retrofit of these present technology prime movers that now require distillate or natural gas fuels. The development is directed toward permitting durable operation on lower grade heavy petroleum fuels with an ultimate capability for conversion to synthetic or alternate fuels when they become commercially available.

The development of an externally-fired Brayton cycle engine capable of virtually complete fuel flexibility is the longer range thrust of the DOE program. These engines will permit powerplant optimization for a variety of domestic fuel resources both liquid and solid. These fuels are typically low-grade petroleum fractions, industrial by-products, forest and agriculture residues, municipal refuse-derived fuels, as well as coal and coal-derived synthetics.

The utilization of these engines in a solar and fossil hybrid mode of operation will not only provide fuel conservation and decreased pollutants, but will also yield an ongoing competitive solar option that can lead to early introduction of solar power systems.

## 3.0 Conclusions

Solar/fossil hybrid gas turbine systems in retrofit or repowering applications to existing simple Brayton cycle combustion turbine peaking powerplants can extend their operation into the intermediate capacity range. This may be an economically attractive solar application with a potentially larger market throughout the U.S. New hybrid system configurations operating in the solar and fossil mode can utilize currently available high temperature, high efficiency Brayton cycle conversion machinery. Advanced configuration hybrid systems have the potential of utilizing future energy conversion subsystems that offer both fuel flexibility and significant increases in conversion efficiency. These systems can serve as a vehicle to transition from today's fossil fuels through intermediate use of heavy residual oils and eventually to coal-derived fuels.

Operation of these fuel-flexible advanced gas turbine engines in a solar and fossil hybrid series augment mode would provide substantial fuel savings during the transition to coal-derived fuels, reduce pollutants and, in addition, could allow an early introduction, on a large scale, of solar collection subsystems. These benefits would accrue because of the favorable economics and potential efficiency advantage of advanced gas turbine hybrid powerplants to solar standalone steam Rankine plants with thermal energy storage.

Table 1

Cost Input Parameters for Economic Comparison

| Powerplant Type | Case | Solar thermal energy collection cost, \$/MJ/sec, (\$/M Btu/yr) | Energy conversion (plant) cost, \$/kWe | Hybrid plant integration cost, \$/kWe | Energy storage cost, \$/MWe sec, (\$/kWe hr) | Fossil fuel cost, \$/GJ (\$/M Btu) | Energy conversion thermal efficiency, percent |
|---|---|---|---|---|---|---|---|
| Advanced hybrid-recuperated gas turbine cycle | A | .83 (28) | 150 | 10 | ----- | 2.37 (2.50) | 50 |
| Retrofit hybrid-simple gas turbine cycle | B | .83 (28) | 150 | 10 | ----- | 2.37 (2.50) | 34 |
| Retrofit hybrid-steam Rankine cycle | C | .83 (28) | 600 | 70 | ----- | 2.37 (2.50) | 40 |
| Solar thermal steam Rankine cycle Low cost energy storage | D | .83 (28) | 600 | | 8.3 (30) | ----- | 40 |
| High cost energy storage | E | .83 (28) | 600 | | 27.8 (100) | ----- | 40 |

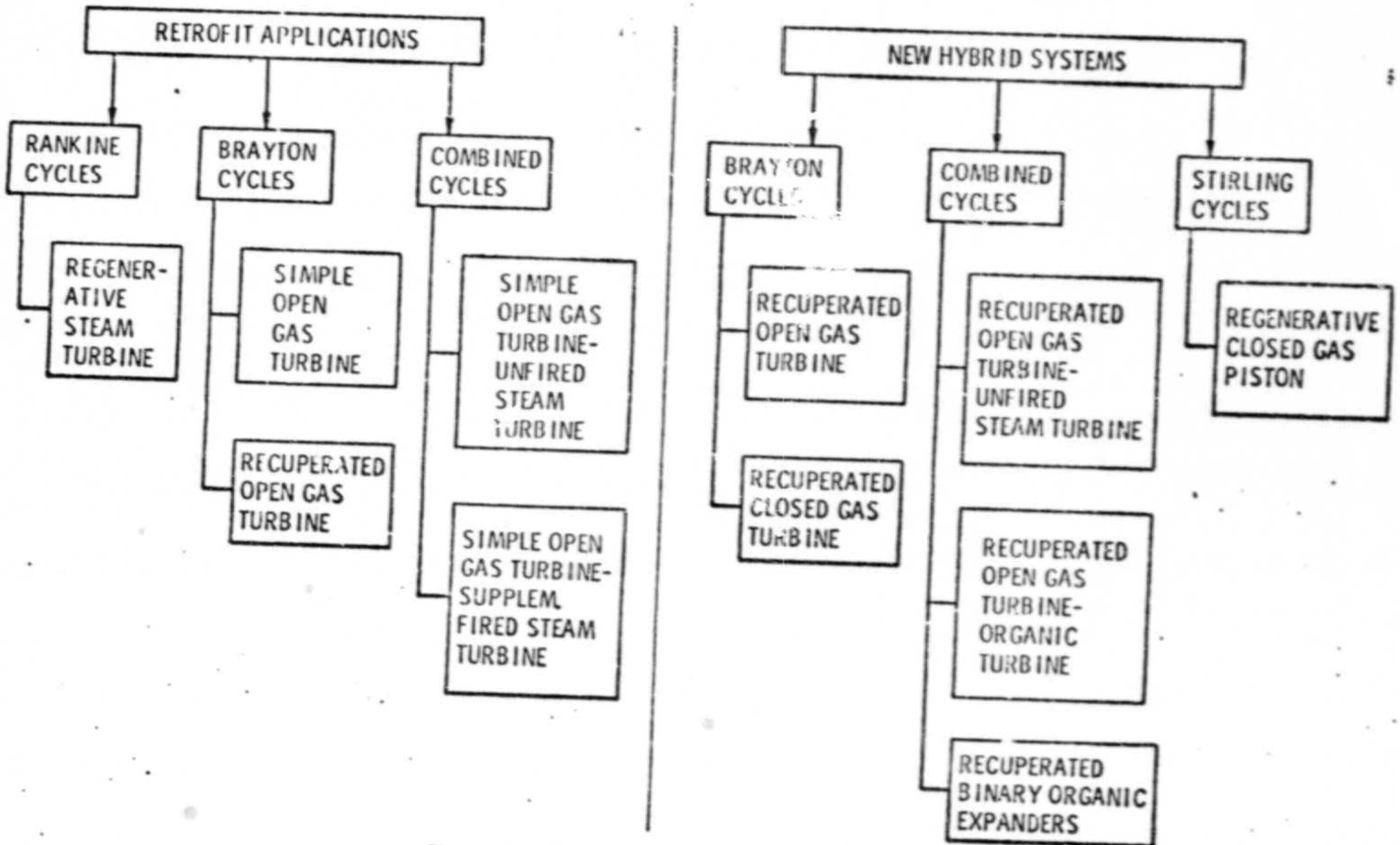


Figure 1. - Solar/fossil hybrid candidate systems.

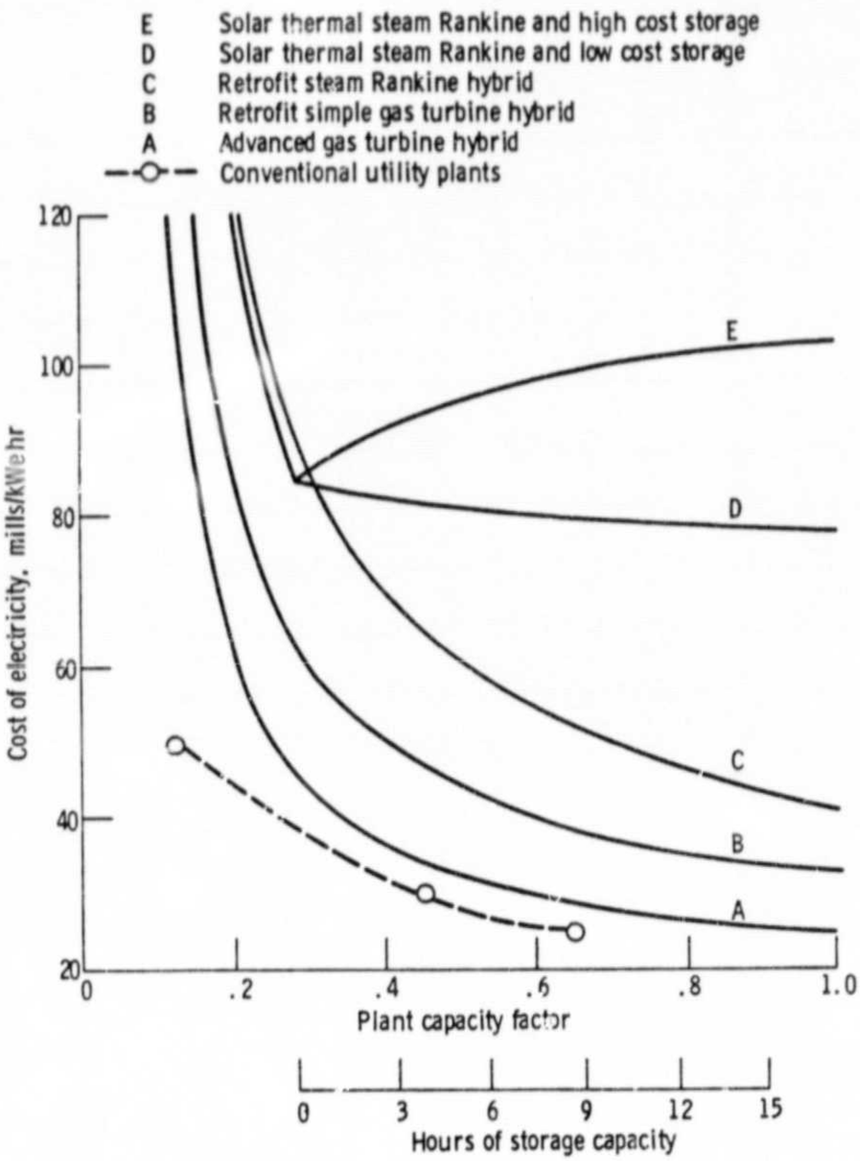


Figure 2. - Overall economic comparison of powerplant types.

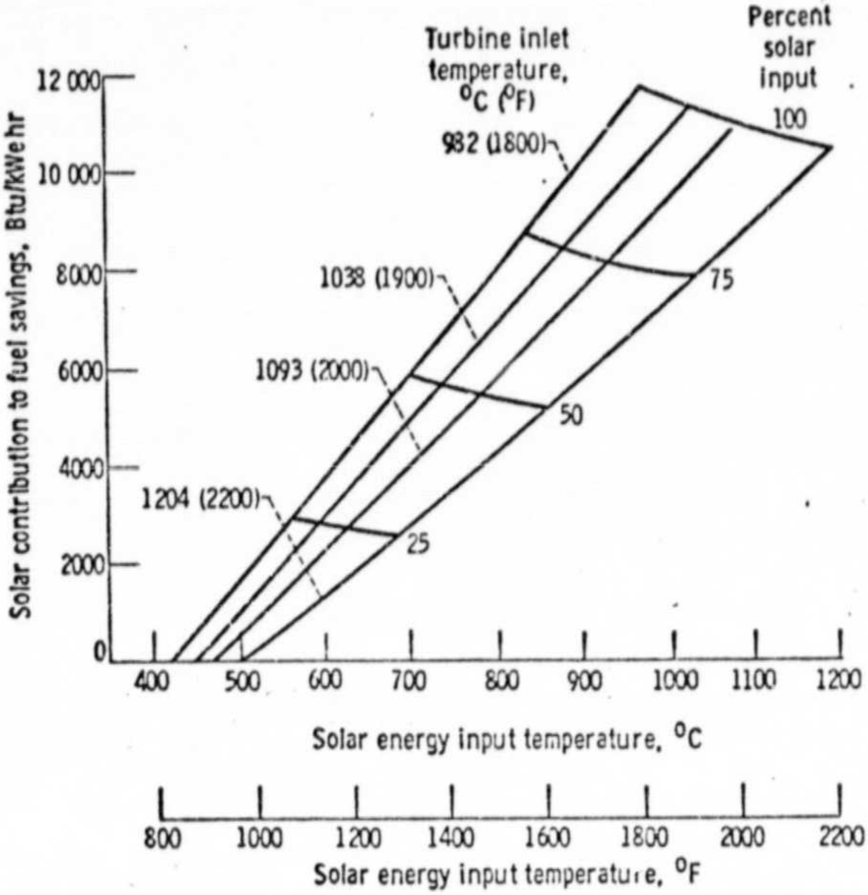


Figure 3. - Fuel savings capability of simple gas turbine open cycle hybrid powerplant.

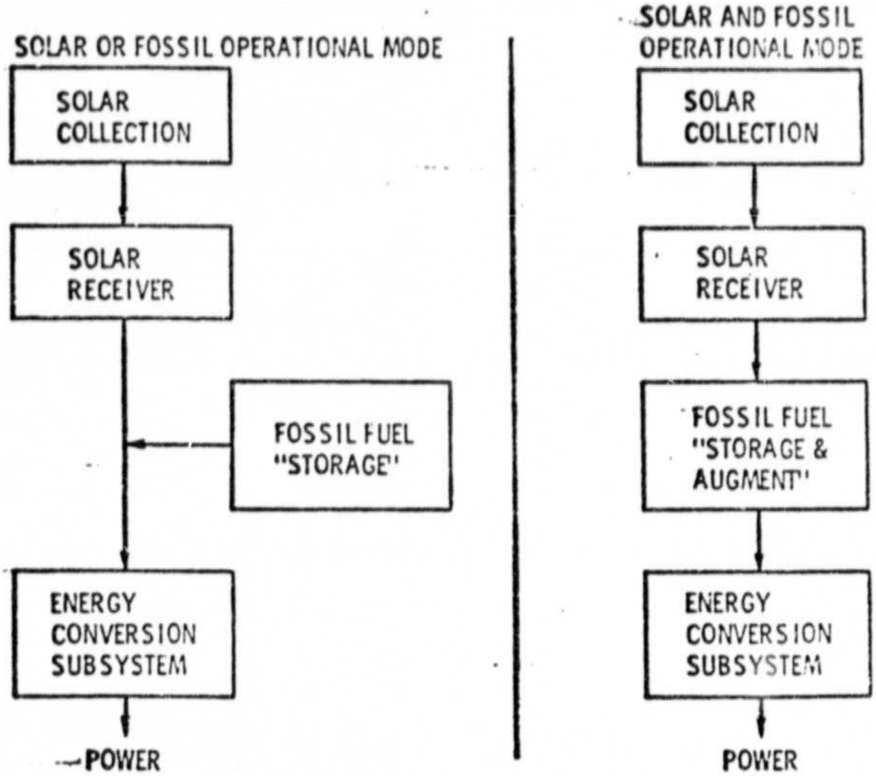


Figure 4. - Solar/fossil hybrid systems operation.

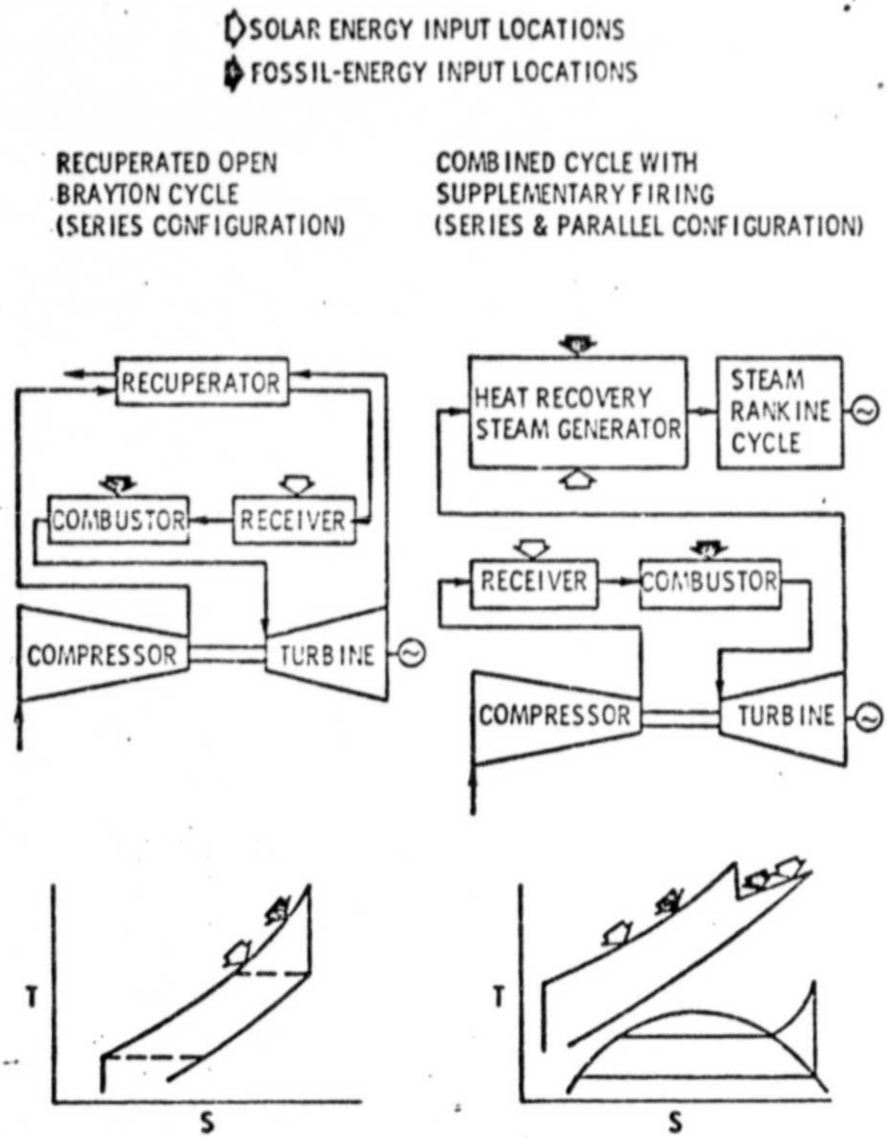


Figure 5. - Hybrid system configuration schematics.