SERI/TP-34-236

AN APPLICATIONS ANALYSIS FOR THE SOLAR INDUSTRIAL PROCESS HEAT MARKET

SHIRLEY STADJUHAR

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APRIL 25-27, 1979

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ABSTRACT

The importance of the industrial process heat market in terms of energy consumption and amenability of this market to solar thermal technology are examined. An analytical method for evaluating solar industrial process heat systems has been developed and implemented in a flexible, fast calculating, computer code -- PROSYS/ECONMAT. The long-term average performance model PROSYS predicts annual energy output for several collector types, including flat-plate, non-tracking concentrator, one-axis tracking concentrator, and two-axis tracking concentrator. The companion computer program ECONMAT calculates the solar equipment cost and generates a life cycle cost analysis. Analytical results demonstrate the software flexibility for use in feasibility and parametric sensitivity studies.

INTRODUCTION

The divergence of increasing United States energy consumption and decreasing domestic supplies of oil and gas along with increased dependence on foreign fuel supply are stimulating the search for alternate energy sources. Among the alternatives solar energy promises to become a primary source of inexhaustible, nonpolluting energy. In order to assess the potential solar energy contribution, the overall U.S. energy consumption pattern must be examined. As shown in Figure 1, the industrial sector clearly emerges as the largest single energy consumer, using 37% of the total U.S. energy demand. From 50% to 70% of this energy is for industrial process heat (IPH) used in the preparation and treatment of manufactured goods and produce (1). Industry thus provides a potentially large market for solar technology but only if the quantity and quality of energy required by IPH applications can be provided by solar energy.

Although industrial process heat requirements span a broad temperature range, a significant amount of heat is used at temperatures which can be provided by currently available solar technology. At least 27% of the IPH requirement is for temperatures below 300C (≈550F) and can be supplied by commercial collectors (2). Using solar energy for preheat and technological developments to supply higher temperatures will increase the percentage of potential solar contribution to as much as 50%.

The use of solar technology for IPH has distinct advantages compared to other applications of solar energy (3). Unlike the mismatched seasonal supply and demand cycles of solar space heating, the industrial requirements are continuous throughout the year. The existence of a conventional backup system allows using the solar energy on an as-available basis, and although storage in some cases may be beneficial, it is not essential. Established industrial maintenance procedures and personnel can be extended to include routine upkeep on the solar system. High energy demands in industry often require large area solar systems, giving an advantage of reduced cost per unit area through the economy of scale effect.

EVALUATING SOLAR TECHNOLOGY FOR PROCESS HEAT

Solar energy for process heat can be supplied directly or through a heat transfer fluid such as hot water, hot air, or low pressure steam. To effectively meet the wide range of IPH temperatures, many generic collector types are required, as shown in Figure 2. Because of the diverse temperature requirements, system configurations, and the variety of available collectors, it is important to select the appropriate solar equipment for the specific IPH application. An analytical approach to this evaluation process has been developed and is termed end-use matching.

Considerations in end-use matching must include process requirements, meteorological effects, solar system characteristics, and economic factors as illustrated in Figure 3. Because of the number of variables and computations involved, the evaluation can be performed most effectively with a computerized analysis. The software developed includes three components: (1) a set of databases; (2) a performance model PROSYS; and (3) an economic evaluation ECONMAT. Figure 4 shows the basic relationship of these components and the flow of the evaluation procedure.

Databases

To represent the information pertinent to a specific solar IPH application, four sets of input data are required. Much of the data is location dependent. In order to have representative coverage for the United States and to have reliable meteorological data, the 26 sites for which SOLMET data exists were chosen. The recent availability of ESATZ data (4) allows expansion to 248 locations.

The meteorological database METDAT specifies the quantity and quality of the available solar radiation at the chosen location. Values are given for a typical day each month and include long-term average daily total radiation on a horizontal surface, clearness number, and day-time ambient average temperature.

The industrial process heat database IPHDB is composed of entries for specific processes and contains for each temperature, heat rate, and flow rate requirements; annual energy used; conventional fuel source; and appropriate system types in order of applicability (3 of a possible 6). Each entry is identified as a four-digit standard industrial classification (SIC) and an optional alphanumeric character if sub-processes are given.

At the present time, 20 collectors are represented in the collector database COLDAT. Of these, eight have performance data derived through tests at the facilities of Sandia Laboratory, Albuquerque (5). Both performance and cost information is given for each collector including optical efficiency, concentration ratio, heat loss coefficients, internal blocking and shading factors, F.O.B. costs, auxiliary costs, and installation labor. Generic collector types represented in COLDAT include flat plate, compound parabolic concentrator, linear fresnel lens, parabolic trough, line focus, and parabolic dish.

The economic database ECONDAT contains site specific information on labor rates and conventional fuel costs including coal, natural gas, fuel oil, and electricity. Propane costs are currently being added. Fuel costs often vary with usage amount, contract status, (firm, interruptible, etc.) and use schedule. In cases where such detailed information is known, the database values can be overridden through card input.

The database information resides on direct access disk files and is accessed through sequential read operations. The time-consuming magnetic tape read operations used in many solar energy models are thus avoided. Random access data retrieval can be incorporated as the database size warrants.

Performance Model PROSYS.

In order to assess the feasibility of solar energy for a specific industrial process, it is necessary first to calculate the amount of energy that can be delivered by the available solar equipment while satisfying the process requirements. The analytical performance model used is based on a method developed by Rabl and Collares-Pereira (6) which predicts the long-term average energy delivered by several generic collector types. Included are the two-axis tracking concentrator, single-axis concentrator, non-tracking concentrator (compound parabolic concentrator), and flat-plate collector. The calculated deliverable energy per unit area for a single collector is adjusted to include losses normal to larger systems. Six system types are modeled including direct hot water, fluid/water heat exchanger, direct hot air, fluid/air heat exchanger, flashed steam and unfired steam generator.

The analytical model is implemented in the computer program PROSYS (Process Heat System Model), yielding a tool with which a variety of solar equipment configurations can be evaluated. As shown in Figure 5, for a given location and an arbitrary number of processes, the annual deliverable energy is calculated for as many as three systems per process and all applicable collectors for each system. PROSYS uses information from the meteorological, industrial process heat, and collector databases to evaluate each process-system-collector combination.

PROSYS is not a dynamic simulation nor a means of detailed system design, but instead a method of predicting long-term average performance. While the nondynamic nature of the model imposes some limitations, it yields the advantages of speed and flexibility. The model provides an efficient method for preliminary appraisal of solar energy for industrial applications, a standard procedure to compare generic collector types, and a rapid means of performing a large number of parametric studies.

At this point in the analytical procedure, the best performing collector and system for each specific process can be selected. However, performance is not the entire answer. The actual winner is the solar equipment that is most cost effective, a criterion which is a blend of both performance and cost. Therefore, the performance data of each combination are stored on the database PERFDAT for subsequent use in the economic analysis.

Economic Evaluation ECONMAT

The basic calculation of the economic analysis is the estimation of the total solar equipment cost. To allow comparison of systems differing in size and annual energy output, an energy capacity cost C($/GJ/yr) is calculated by dividing the total equipment cost by the annual delivered energy. Additional economic evaluation may include calculation of life cycle levelized energy cost and net present value (7).

As shown in Figure 6, the computer program ECONMAT implements the analysis using the precalculated performance data from PERFDAT, the collector costs from COLDAT, and labor rates from ECONDAT. Given the annual energy use and the deliverable energy per unit area of collector, the required collector array area is calculated. Total solar equipment cost is estimated including collector, auxiliary equipment, installation, and system costs.

Levelized energy cost and net present value depend on economic factors that may vary from case to case. The software contains typical default values for economic parameters such as 12% internal rate of return; 6% general inflation rate; 5% add-on fuel escalation rate; annual operation, maintenance, property tax and insurance at 2% of initial investment; 50% corporate income tax rate; 20-year system lifetime; and 20% tax credit. Appropriate local fuel price is obtained from ECONDAT. All default economic factors, including fuel price and labor rate, may be overridden by user input.

To allow system size variation for a specific process and to demonstrate the economy of scale effect, all calculations are shown for 10 incremental energy levels, the maximum of which is the annual energy use specified in the IPHDB. Hence, a large number of computations are required to evaluate each process-system-collector combination at ten energy increments, and a large output results. To facilitate analysis, an option is provided to print only the results for the most economic collector per system.

SOFTWARE SPECIFICATIONS

PROSYS/ECONMAT are written in Fortran for the CDC Cyber or 6000 Series computer. The code for PROSYS contains approximately 1700 lines and requires 60,000 octal words of core for execution. ECONMAT code is only 600 lines and requires 36,000 octal core for execution. Execution times for the combined PROSYS/ECONMAT analysis range from less than 10 seconds for a single process evaluation to several minutes for a set of approximately 50 processes.

ANALYTICAL RESULTS

The analytical tools PROSYS/ECONMAT allow comparison of a variety of collectors for diverse process requirements and quick selection of the solar equipment most suitable in both cost and performance for a specific process. The software can be used for many types of analysis merely by varying the information in the databases. A ranking of solar IPH applications for El Paso, Texas, shown in Figure 7,was generated using an IPHDB containing average parameter values for many "typical" industrial plants. Conversely, actual case studies which provide detailed process breakdown, preheat potential, and/or process reconfiguration can be analyzed with an IPHDB containing specific process data.

An assortment of parametric sensitivity studies can be performed including studies of the effects caused by changes in collector characteristics, costs and economic factors. A comparison of the performance of five collector types over a range of temperatures is illustrated graphically in Figure 8. The same comparison including economic factors in Figure 9 yields a measure of collector cost effectiveness over a range of temperatures.

The net present value of a potential solar system is highly dependent on the price of the industry's conventional fuel source, as shown in Figure 10. The net present value analysis for fluid milk production in El Paso, Texas, shows positive values when the conventional fuel price is greater than $4.00/GJ.

CONCLUSIONS

The industrial process heat sector appears to be a large potential market for solar energy applications. Because of the variety of process requirements and available solar equipment, the evaluation of solar technology for IPH is a complex procedure most easily accomplished by the use of computerized analysis. The PROSYS/ECONMAT software was developed to provide this capability. The software is a powerful analytical tool providing an efficient method for appraising the feasibility of solar technology for industrial process heat applications.

The work described herein has been sponsored by the U.S. Department of Energy under contract EG-77-C-01-4042. More complete information on this project is pending publication in a SERI report on industrial process end-use matching (8).

REFERENCES

1. Copeland, R. J., Technology Development Needs for High Temperature Process Heat, SERI/TR-35-047, Solar Energy Research Institute, Golden, Colorado, August, 1978.

2. Fraser, M. C., Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat, ERDA/InterTechnology No. 00028-1, InterTechnology Corporation, Warrenton, VA., 1977.

3. Putting the Sun to Work in Industry, SERI/SP-34-175, Solar Energy Research Institute, Golden, Colorado, 1979.

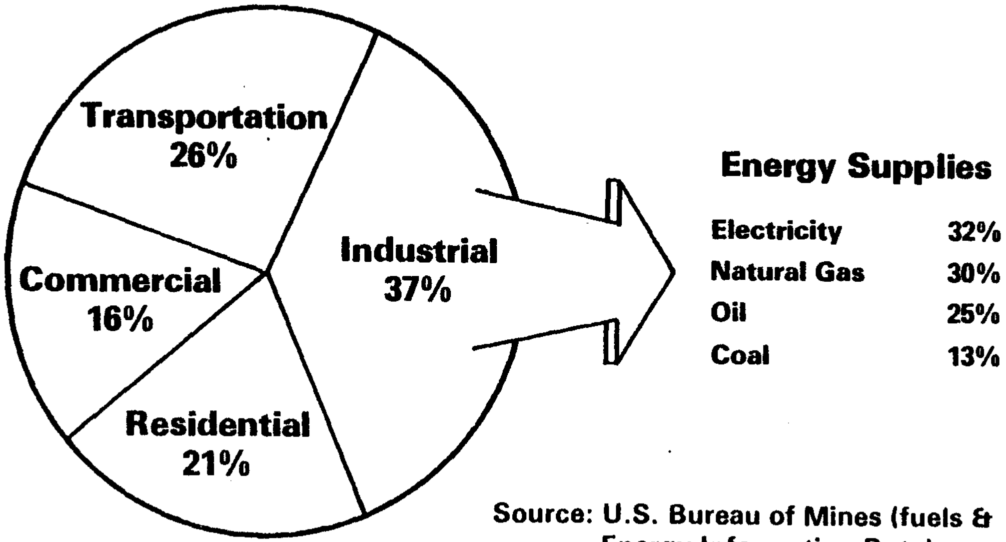
4. Cinquemani, V., Input Data for Solar Systems, USCOMME-NOAA-Asheville, N.C. 12/78/1000, National Climatic Center, Asheville, N.C., November, 1978.

5. Dudley, V. E., Summary Report: Concentrating Solar Collector Test Results, Collector Modular Test Facility, SAND78-0815, Sandia Laboratories, Albuquerque, N.M., May, 1978.

6. Collares-Pereira, M. and Rabl, A., Simple Procedure for Predicting Long-Term Average Performance of Nonconcentrating and of Concentrating Solar Collectors, ANL-78-67, Argonne National Laboratory, Chicago, IL., June, 1978.

7. Dickinson, W.C. and Freeman, H.J., An Economic Methodology for Solar-Assisted Industrial Process Heat Systems: The Effects of Government Incentives, UCRL-52254, Lawrence Livermore Laboratory, Livermore, CA., June, 1977.

8. Brown, K.C., et al., End Use Matching for Solar Industrial Process Heat, SERI/TR-34-091, Solar Energy Research Institute, Golden, Colorado, (In Preparation).



Source: U.S. Bureau of Mines (fuels & Energy Information Data); U.S. Bureau of Census (Annual Survey of Manufacturers, 1976)

Figure 1. Distribution of Energy Demand Among Major Consuming Sectors

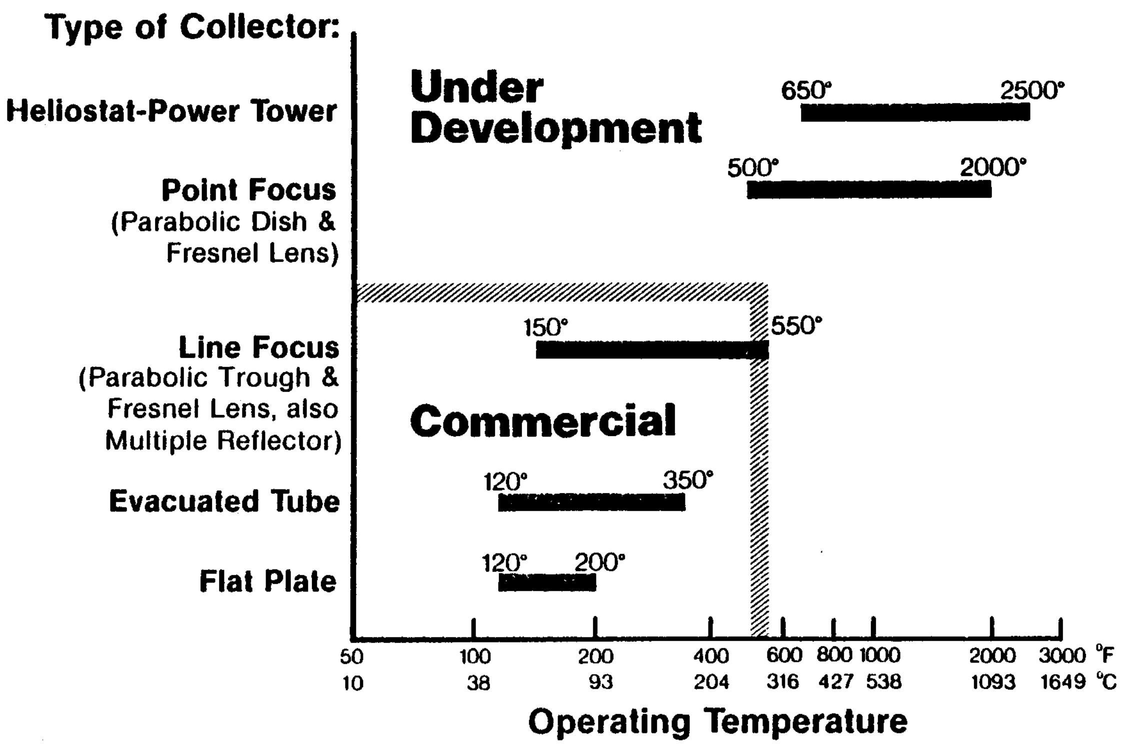


Figure 2. Typical Operating Temperature Ranges of Solar Collectors

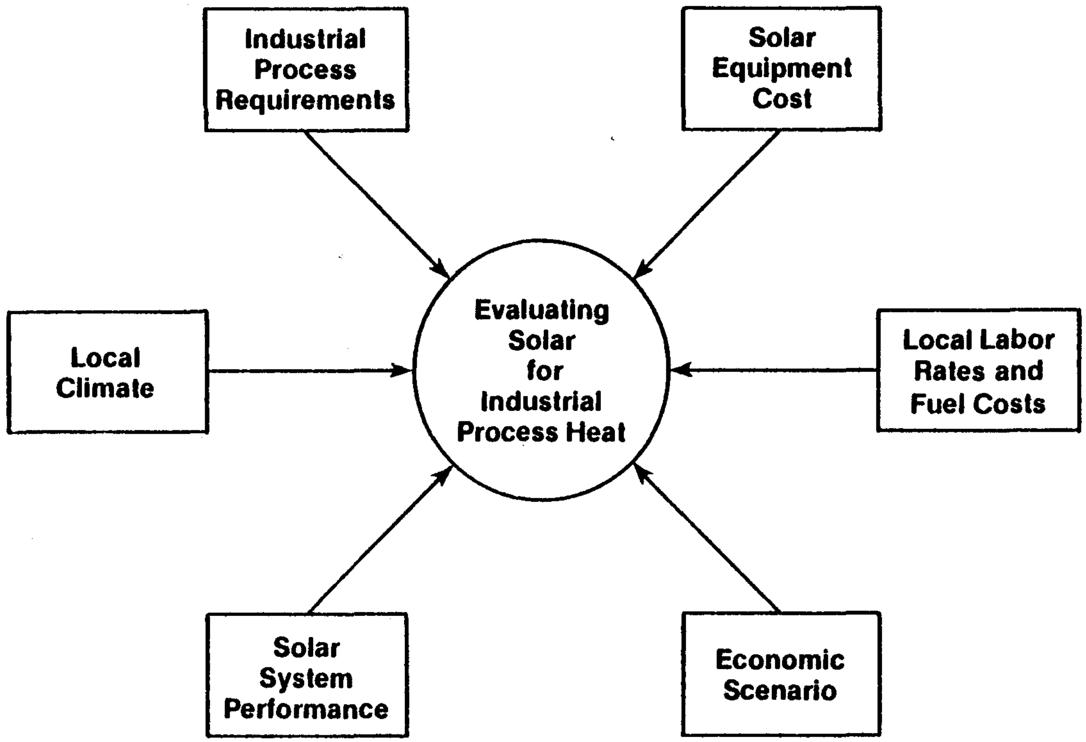


Figure 3. Key Variables in Evaluation of Solar Industrial Process Heat

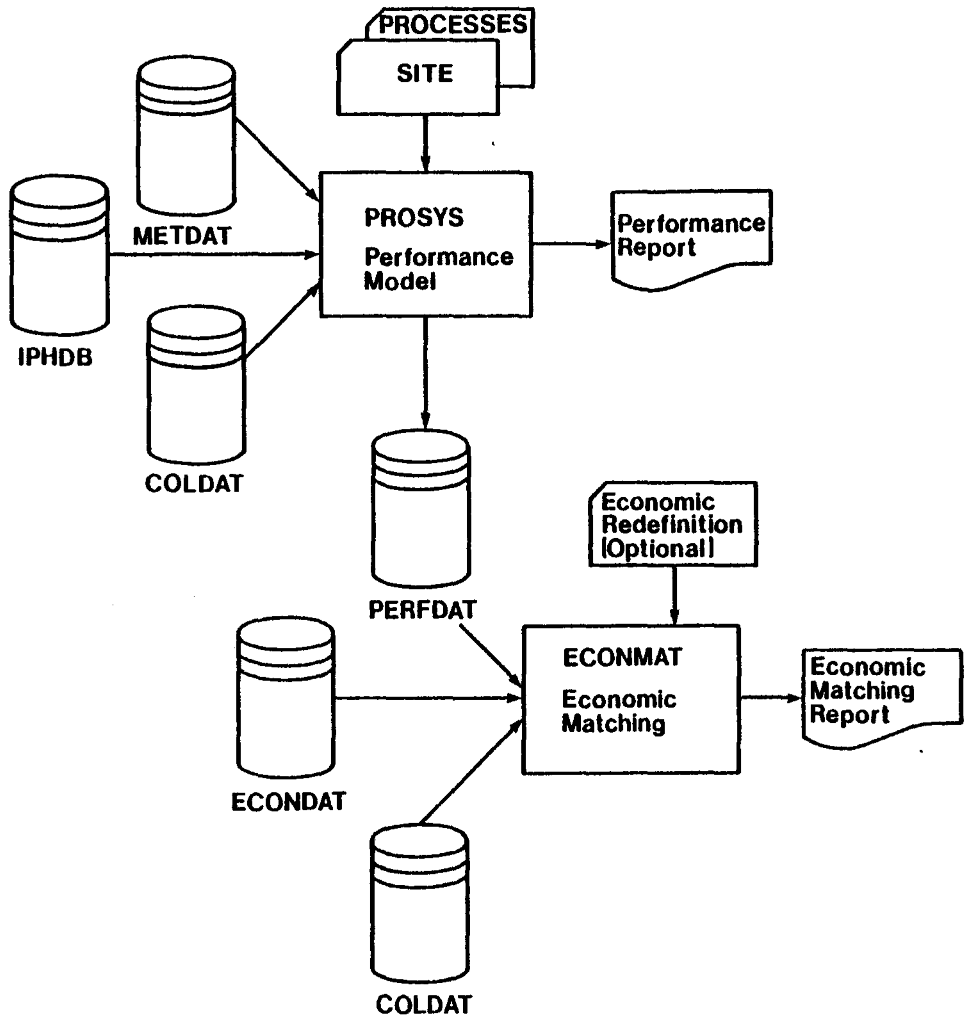


Figure 4. Methodology for End-Use Matching

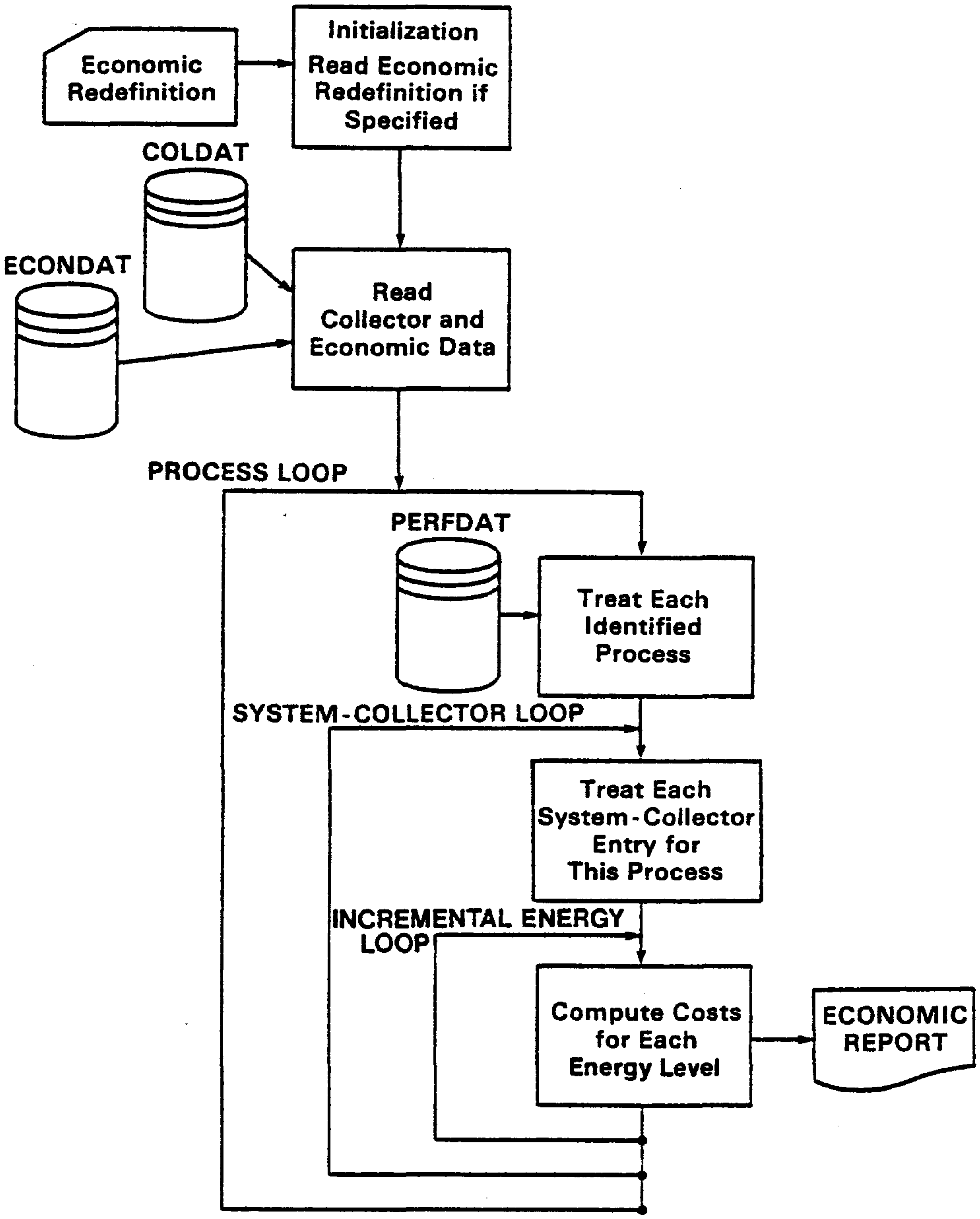


Figure 5. PROSYS Logic Flow Diagram

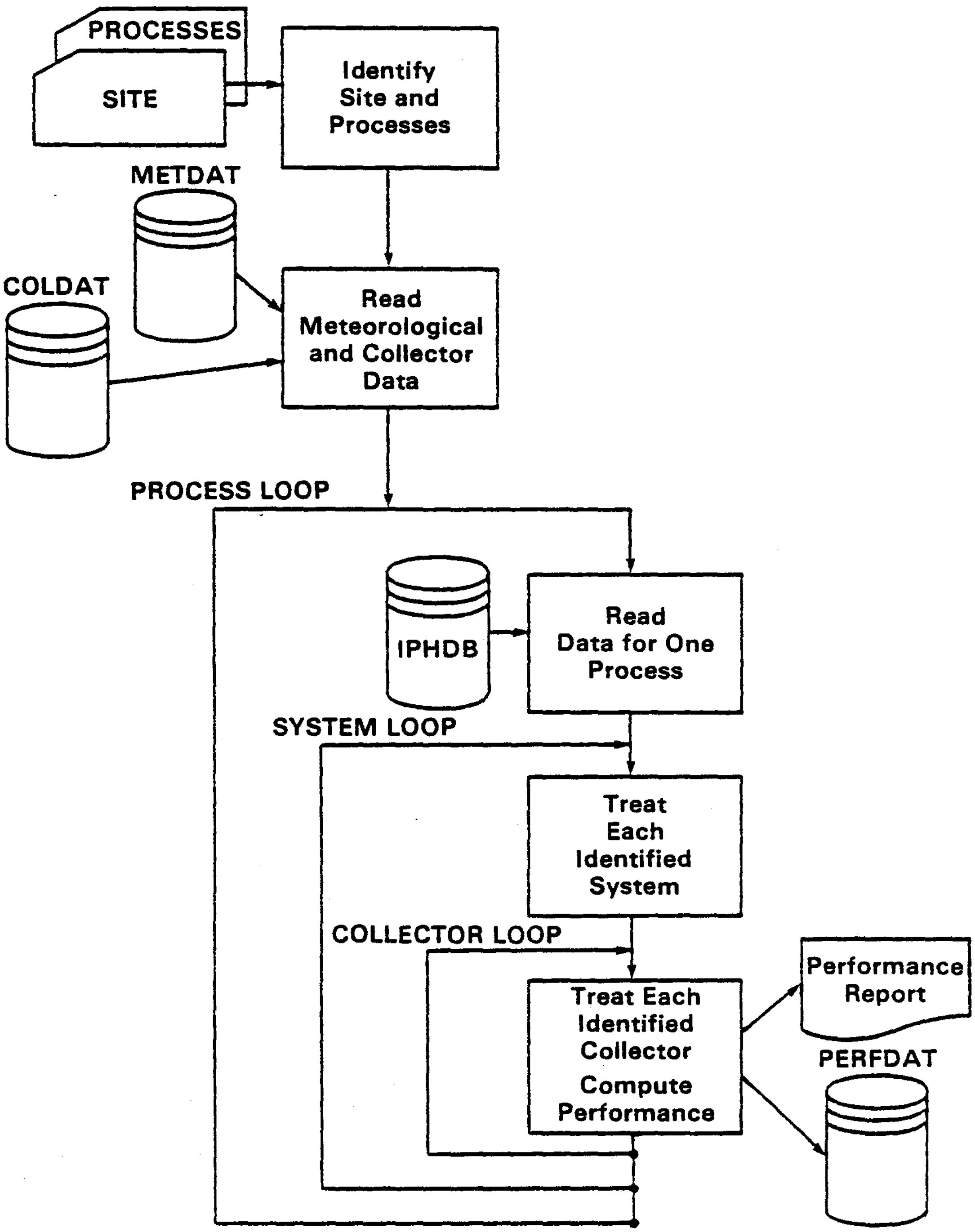


Figure 6. ECONMAT Logic Flow Diagram

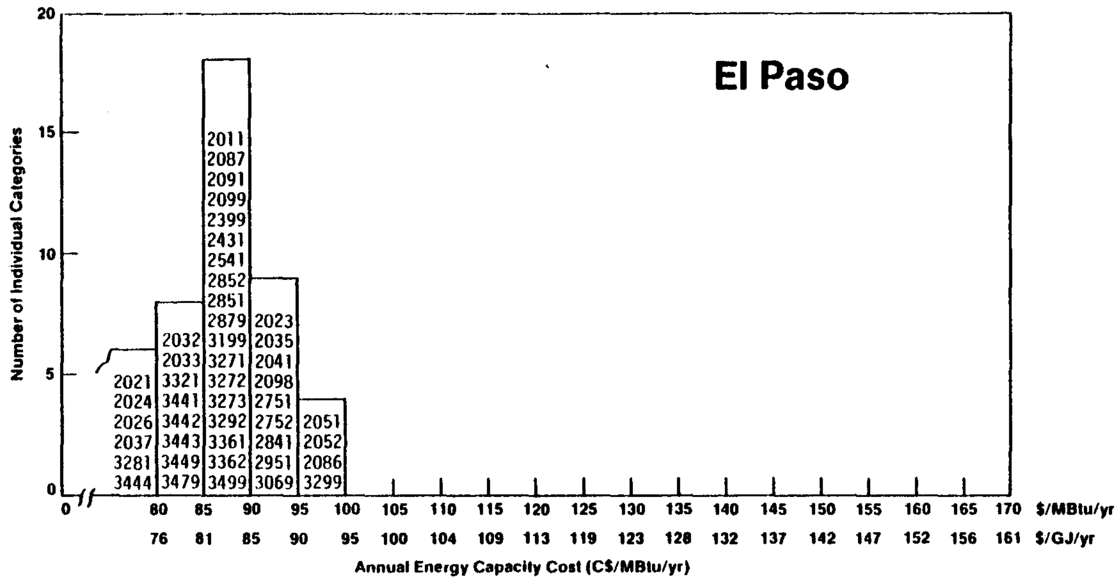


Figure 7. Ranking of Solar IPH Applications in El Paso on the Basis of Energy Capacity Cost

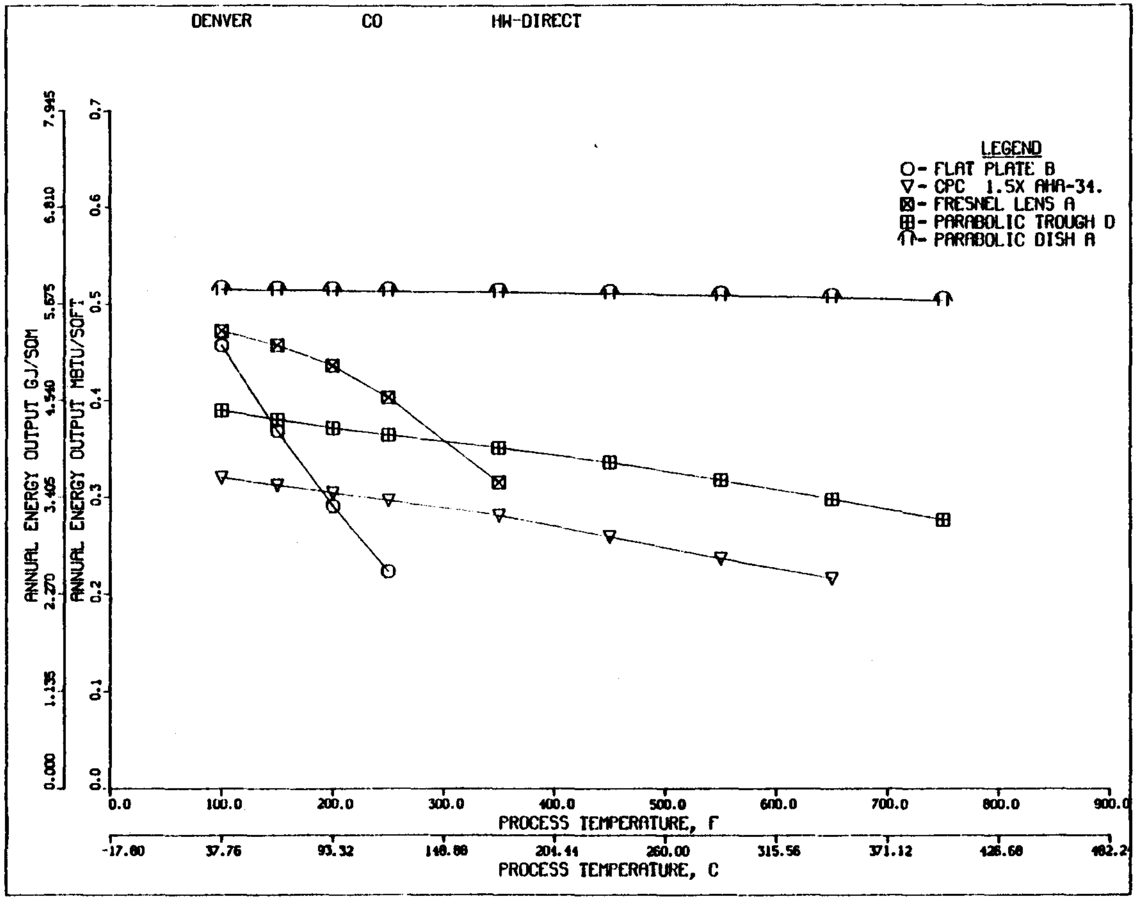


Figure 8. Annual Energy Output of Several Collector Types over a Range of Temperatures

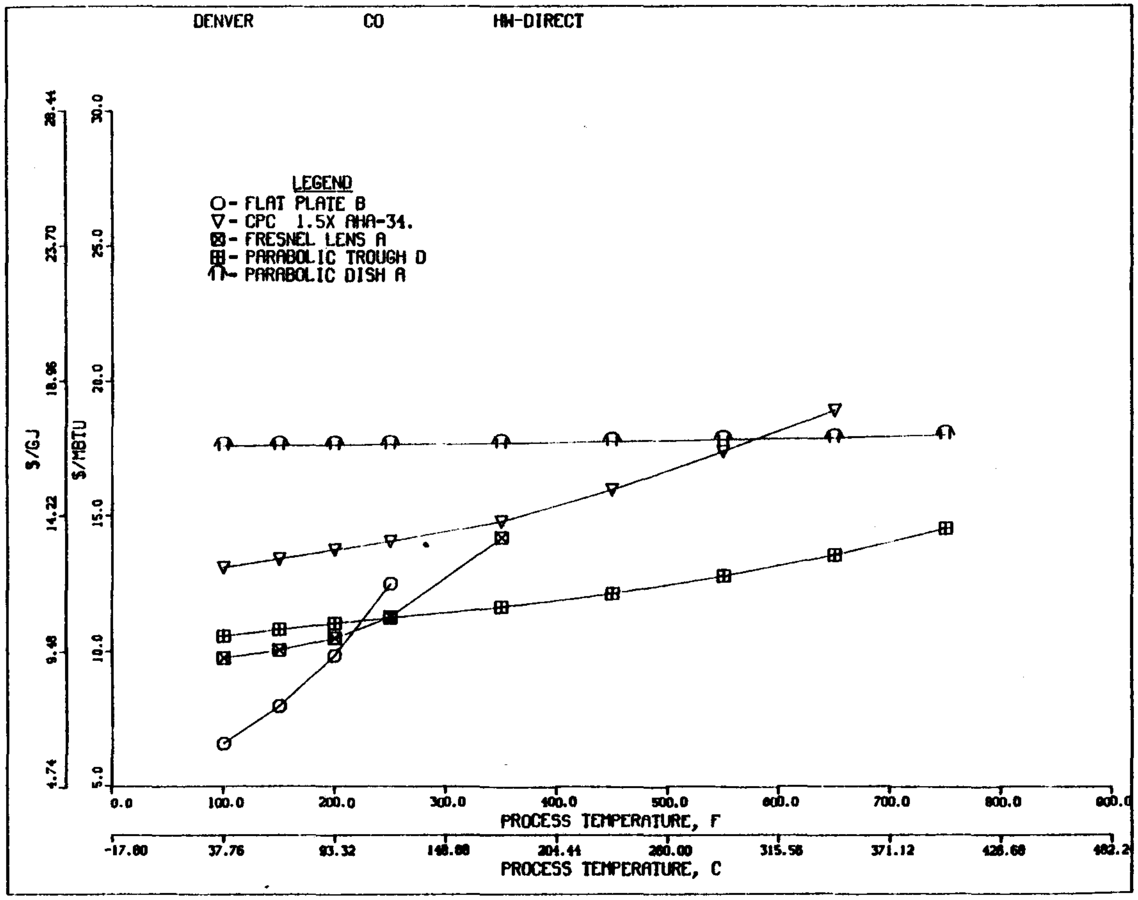


Figure 9. Levelized Energy Cost for Several Collector Types over a Range of Temperatures

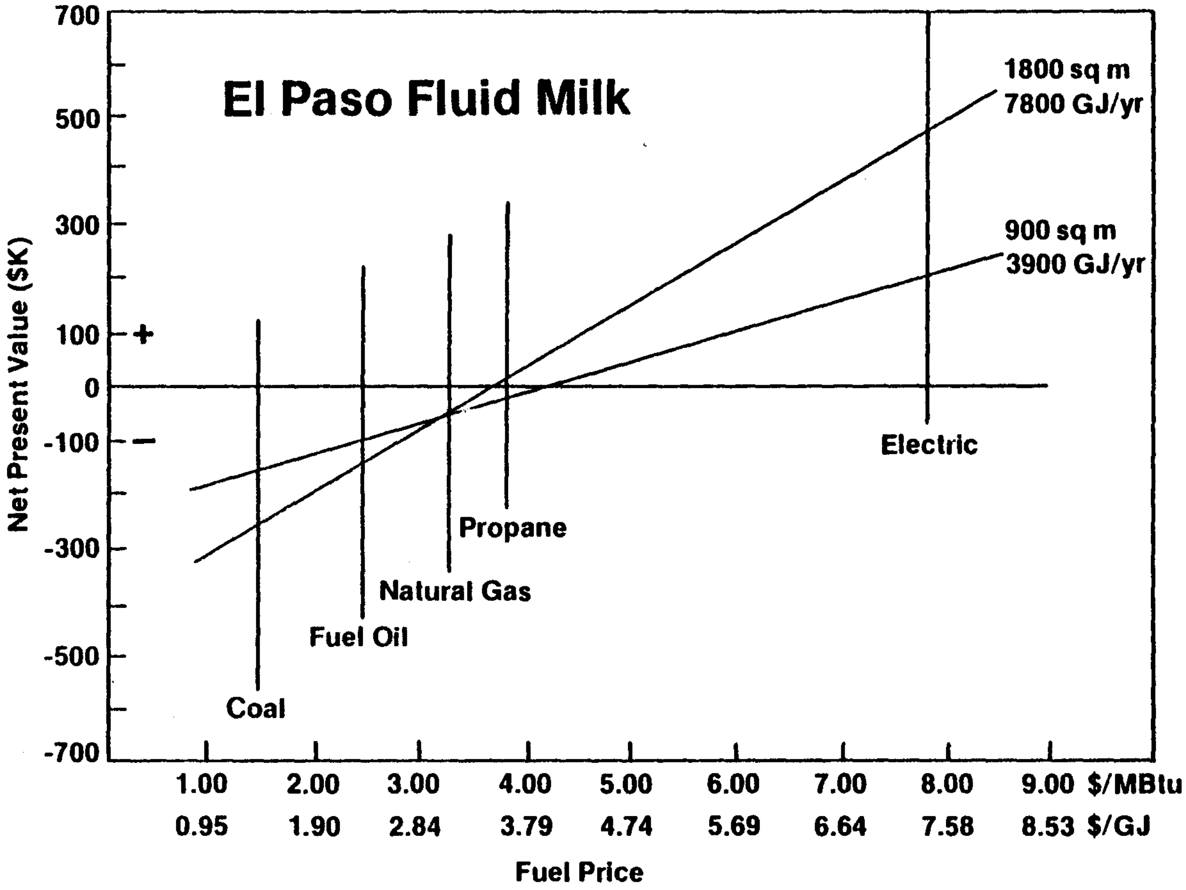


Figure 10. **Net Present Value of Solar Applied to Fluid Milk Proessing in El Paso for a Range of Fuel Prices**

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