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FEASIBILITY EVALUATION FOR SOLAR INDUSTRIAL PROCESS HEAT APPLICATIONS

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ABSTRACT

An analytical method for assessing the feasibility of Solar Industrial Process Heat applications has been developed and implemented in a flexible, fast-calculating computer code—PROSYS/ECONMAT. The performance model PROSYS predicts long-term annual energy output for several collector types, including flat-plate, nontracking concentrator, one-axis tracking concentrator, and two-axis tracking concentrator. Solar equipment cost estimates, annual energy capacity cost, and optional net present worth analysis are provided by ECONMAT. User input consists of detailed industrial process information and optional economic parameters. Internal program data includes meteorological information for 248 U.S. sites, characteristics of more than 20 commercially available collectors representing several generic collector types, and defaults for economic parameters. Because a full-scale conventional back-up fuel system is assumed, storage is not essential and is not included in the model. Although the software is neither a dynamic simulation nor a detailed design tool, it yields the advantages of speed and flexibility and provides a method for uniform comparison of diverse solar equipment, IPH applications, and locations. Recent updates in performance calculations, the collector array sizing algorithm, and system cost estimates have improved the accuracy of the PROSYS/ECONMAT evaluation. Efforts in IPH model comparison and PROSYS/ECONMAT validation have been initiated. The PROSYS/ECONMAT code has been used in a variety of the case studies, in-depth applications analyses, and generic system studies. Examples of such analyses demonstrate the capabilities of the model.

INTRODUCTION

The industrial sector is the largest single U.S. energy consumer, using 37% of the total national 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 that can be provided by currently available solar technology. At least 27% of the IPH requirement is for temperatures below 300°C (550°F) 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%.

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 Fig. 1. 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. Considerations in the selection of the most effective solar equipment must include process requirements, meteorological effects, solar system characteristics, and economic factors, as illustrated in Fig. 2. Because of the number of variables and computations involved, the evaluation can be performed most efficiently with a computerized analysis.

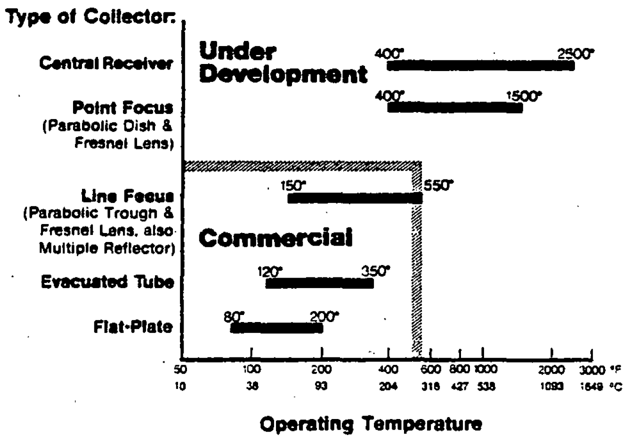

Figure 1. Typical Operating Temperature Ranges of Solar Collectors

EVALUATION PROCEDURE

Software developed for the analysis of solar IPH applications includes the performance model PROSYS, the economic evaluation ECONMAT, and several attendant data bases. Figure 3 shows the basic relationship of these components and the flow of the evaluation procedure. The main features of the PROSYS/ECONMAT code are summarized in Table 1 and expanded in the following sections.

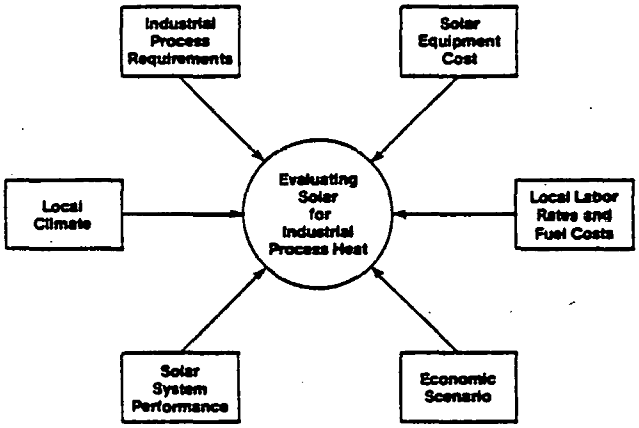

Figure 2. Key Variables in Evaluation of Solar Industrial Process Heat

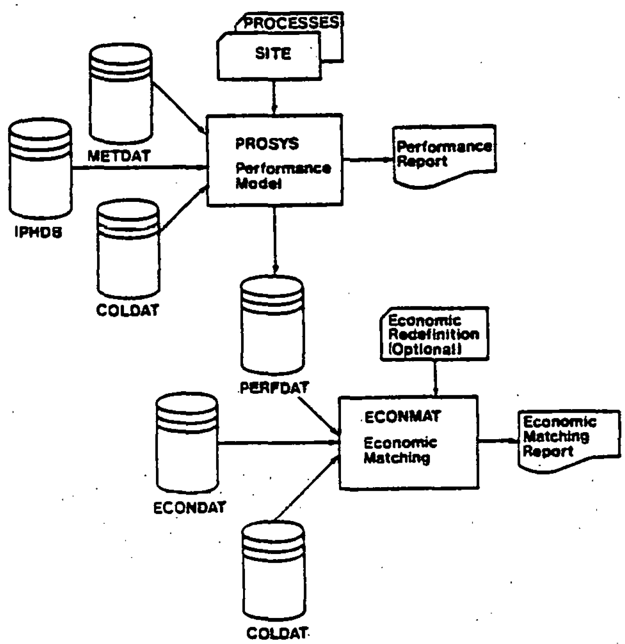

Figure 3. Flow of Evaluation Procedure

DATA BASES

Characterization and analysis of solar IPH applications require site-specific meteorological data, detailed industrial process information, solar equipment performance and cost data, and appropriate economic parameters. This information resides on four data bases - METDAT, IPHDB, COLDAT, and ECONDAT.

Table 1. Features of the PROSYS/ECONMAT Code

Purpose:	Provide method to assess feasibility of solar IPH applications.
User Input:	Detailed industrial process information and optional economic parameters.
Internal Data:	Meteoroligcal information for 248 U.S. sites.
	Characteristics of several generic collector types.
	Defaults for economic parameters.
Program Output:	Long-term average performance prediction for each collector process combination.
	Estimate of solar system cost and annual energy capacity cost. Optional present worth analysis.
Advantages:	Flexible, high-speed evaluation.
	Uniform comparison of diverse solar equipment, IPH applications, and locations.
Restrictions:	Nondynamic analysis.
	Not a detailed design tool.
	Conventional fuel backup assumed, no consideration of storage.

The meteorological data base (METDAT) specifies the quantity and quality of the available solar radiation at 248 U.S. locations as determined by availability of SOLMET and ERSATZ data [3]. Values are given for a typical day each month and include long-term average daily total radiation on a horizontal surface, clearness number, daytime ambient average temperature, and cloudiness index K_T for each location.

The industrial process heat data base (IPHDB) is composed of entries for specific processes and contains for each of them: temperature, heat rate, and flow rate requirements; conventional fuel source and efficiency; 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 subprocesses are given.

At the present time, 20 collectors are represented in the collector data base (COLDAT). Of these, eight have performance data derived through tests at the facilities of Sandia Laboratory, Albuquerque [4]. 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 data base (ECONDAT) contains site-specific information on labor rates and conventional fuel costs, including coal, natural gas, fuel oil, electricity, and propane. Fuel costs often vary with usage amount, contract status (firm, interruptible, etc.), and use schedule. In cases where such detailed information is known, the data base values can be overridden through card input.

PERFORMANCE MODEL PROSYS

In order to assess the feasibility of solar energy for a specific industrial process, it is first necessary to calculate the amount of energy that can be delivered by the available solar equipment while satisfying the process requirements. The analytical performance model applies a method developed by Rabl and Collares-Pereira that predicts the long-term average energy delivered by several generic collector types. This procedure is based on the classical utilizability concept originated by Hottel, Whillier, Liu, and Jordan [5,6] for flat-plate collectors. Rabl and Collares-Pereira have generalized and simplified the method by including other collector types and defining the utilizability with respect to the day rather than the hour [7,8].

Collectors that are modeled include the two-axis tracking concentrator, single-axis concentrator, nontracking 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 exchange, direct hot air, fluid/air heat exchange, 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 varity of solar equipment configurations can be evaluated. PROSYS is neither 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.

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 [\$/(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, net present value, simple payback period, and break-even fuel price [9,10].

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 process demand heat rate and the collector peak delivery rate, the collector array is sized such that all energy supplied by the solar system is used by the process and no excess energy is produced. Total solar equipment cost is estimated including collector, auxiliary equipment, installation, and system costs.

The optional net present value analysis depends 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 ten incremental energy levels. 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.

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 data bases. A ranking of solar IPH applications for a given location can be generated by using an IPHDB containing average parameter values for many "typical" industrial plants. Conversely, actual case studies that provide detailed process breakdown, preheat potential, and/or process reconfiguration can be analyzed with an IPHDB containing specific process data.

A subprocess can be characterized and its solar potential appraised over the entire U.S. region in an in-depth analysis. For example, consider a pastuerization process at 169°F operating six days per week, producing approximately 3000 gal/hr, with process heat provided by a conventional steam boiler at 65% efficiency. Evaluation of solar process heat provided by horizontal parabolic trough collectors tracking about the N-S axis in an indirect hot water configuration was performed for 27 locations [11]. Figure 4 shows the required fuel price in 1979 \$/MBtu for a 10-year payback for 1979, 1985, and 1990 system start-up times.

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 Fig. 5.

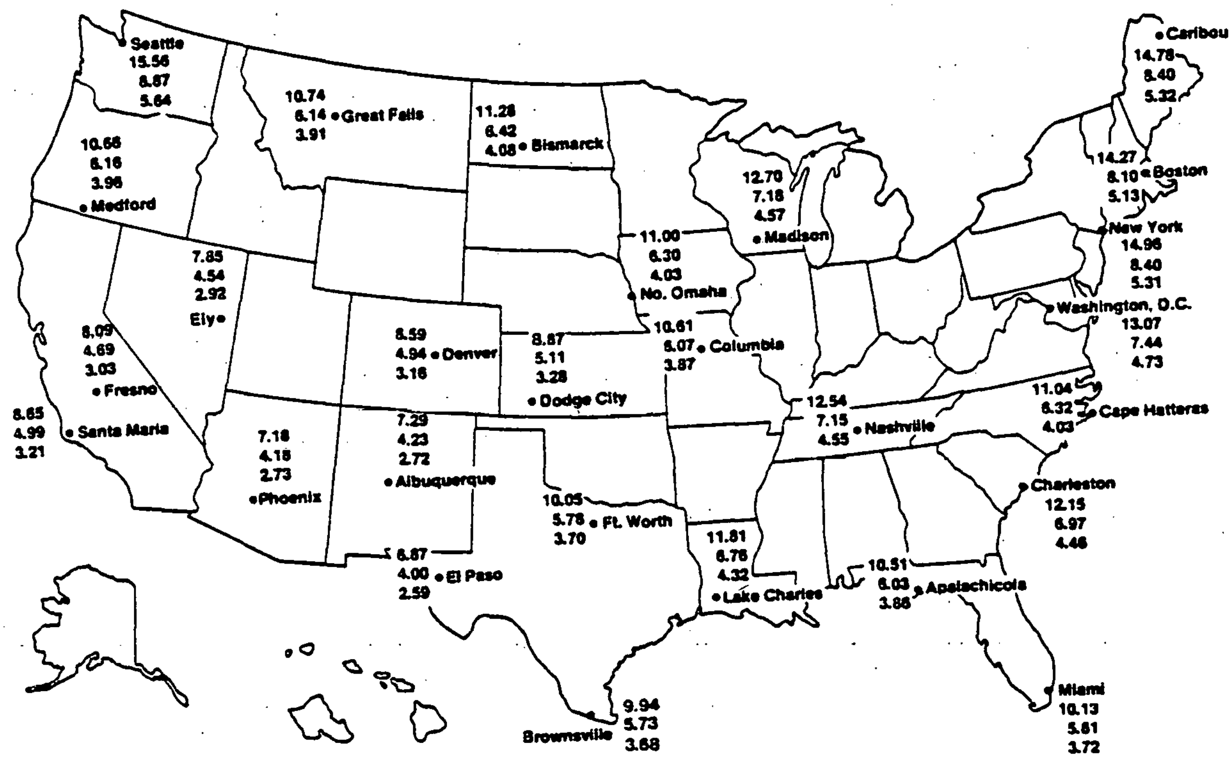

Figure 4. Required Fuel Price in 1979 Dollars/MBtu for a Ten Year Payback.
(Upper Number—1979 Startup: Middle Number—1985 Startup; Bottom Number—1990 Startup)

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 originated to provide this capability.

Extensive application in end-use matching, case studies and in-depth analysis has provided excellent review and program checkout. Improvements in performance calculations and system cost estimates, and updates in collector data, will improve model accuracy. The software provides a powerful analytical tool for an efficient method in appraising the feasibility of solar technology for industrial process heat applications.

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ACKNOWLEDGEMENT

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REFERENCES

1. Copeland, R. J., Technology Development Needs for High Temperature Process Heat, SERI/TR-35-047, Solar Energy Research Institute, Golden, CO, 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. Cinquemani, V., Input Data for Solar Systems, USCOMME-NOAA-Asheville, N.C. 12/78/1000, National Climatic Center, Asheville, NC, November, 1978.

4. Dudley, V. E., Summary Report: Concentrating Solar Collector Test Results, Collector Modular Test Facil-

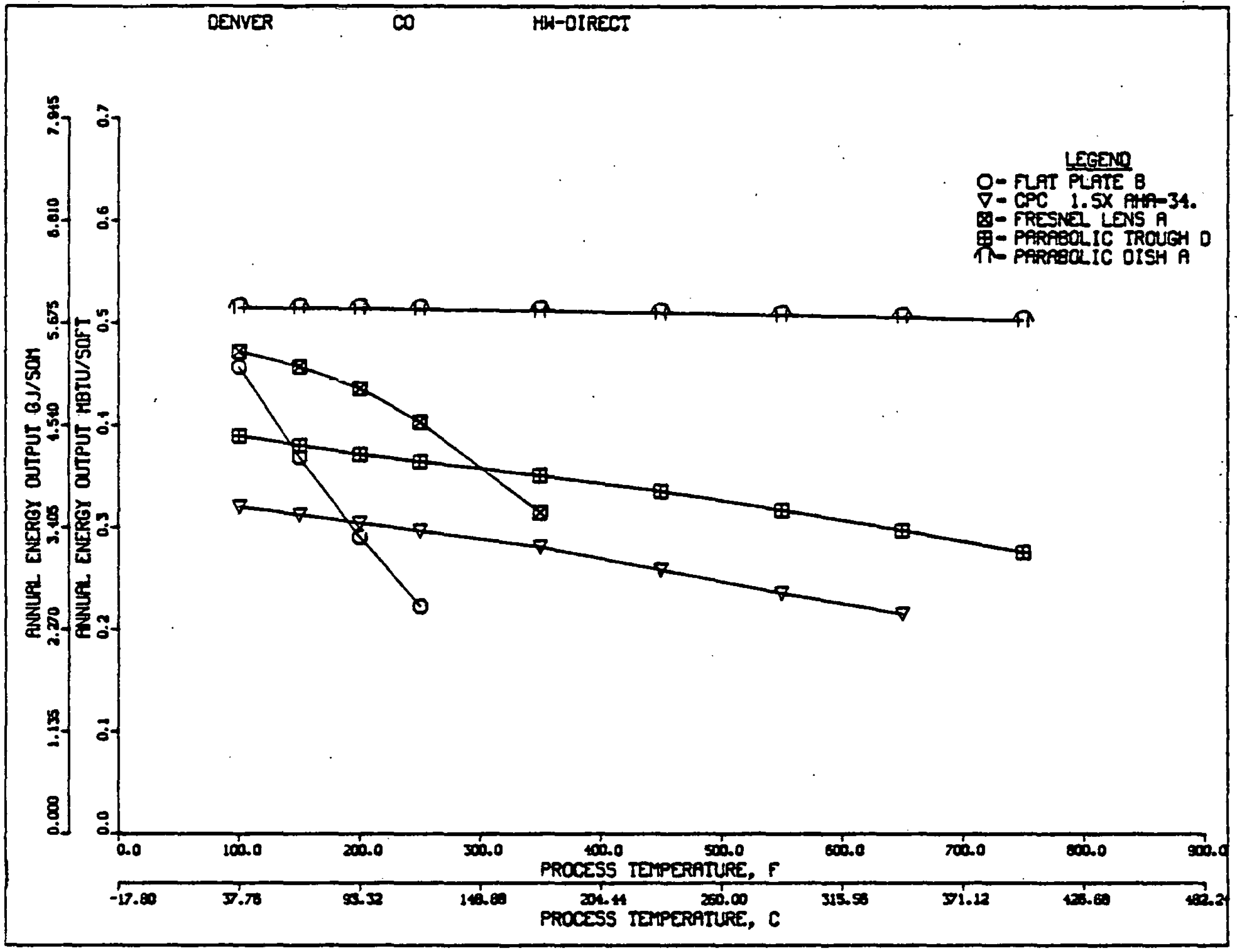

Figure 5. Annual Energy Output of Several Collector Types over a Range of Temperatures

ity, SAND 78-0815, Sandia Laboratories, Albuquerque, NM, May, 1978.

5. Hottel, H. C. and Whillier, A., "Evaluation of Flat-Plate Solar Collector Performance," Transactions of the Conference on the Use of Solar Energy: The Scientific Basis, Vol. II, Part I, Section A, pp. 74-104 (1955).

6. Liu, B. Y. H. and Jordan, R. C., "A Rational Procedure for Predicting the Long Term Average Performance of Flat-Plate Solar-Energy Collectors," Solar Energy 7, 53 (1963).

7. Collares-Pereira, M. and Rabl, A., "Simple Procedure for Predicting Long Term Average Performance of Nonconcentrating and of Concentrating Solar Collectors," Solar Energy 23, No. 7 (1979).

8. Collares-Pereira, M., and Rabl, A., "Derivation of Method for Predicting Long Term Average Energy Delivery of Solar Collectors, Solar Energy 23, No. 7 (1979).

9. 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.

10. Dickinson, W. C. and Brown, K. C., Economic Analysis of Solar Industrial Process Heat Systems: A Methodology to Determine Annual Required Revenue and Internal Rate of Return. UCRL-52814. Livermore, CA: Lawrence Livermore Laboratory, August 1979.

11. Brown, K. C. et al., Industrial Applications Analysis, Market Characterization and System Definition for Several Industries, Proceedings 1979 Industrial Process Heat Conference, SERI/TP-353-467, Solar Energy Research Institute, Golden, CO, Oct. 1979.

12. Brown, K. C., et al., End-Use Matching for Solar Industrial Process Heat, SERI/TR-34-091, Solar Energy Research Institute, Golden, CO, Jan. 1980.