ABSTRACT
Solar thermal systems capable of providing process heat to the industries that make up the Food and Kindred Products Group are now commercially available. Whether or not they will be adopted by these industries will depend not only upon further reductions in capital costs, but also upon the costs and availability of alternative fossil fuels, the operating and maintenance costs of solar thermal systems, and tax incentives.

INTRODUCTION
Research and development work in solar energy technologies gained a new momentum in 1973. The cause célèbre was the oil embargo by the OPEC nations and the resultant economic strains felt throughout the world. In the years that followed, the industrialized countries such as the United States, Canada, France, Western Germany and Japan increased their solar R & D budgets manyfold. For example, in the United States alone, the Federal solar R & D budget rose from $15 million in 1974 to $600 million in 1981. A survey conducted by the United Nations reported that during the post-oil-crisis period, 57 developing countries undertook some kind of nonconventional energy resources assessment program. Since 1973, the UN and other world agencies have funded 158 programs with an aggregate funding of $148 million. Bilateral assistance in nonconventional energy has also increased considerably during the same period. Brazil, Canada, Egypt, France, West Germany, India, Italy, The Netherlands, Norway, Saudi Arabia, the United Kingdom and the USSR participated in such projects. The general conclusion to be drawn from these and other data is that there is a worldwide upsurge of activities in solar and other renewable energy technologies and that the activities will have a significant impact on the energy market sector in the years ahead.

In the United States, solar energy research and development has culminated in a determined attempt to commercialize photovoltaic and solar thermal systems. In this paper we will describe one such system on which we in Foster Wheeler have been working: a parabolic trough solar thermal system.

COLLECTOR FUNDAMENTALS
Concentrating collectors utilize reflectors or refractors to increase the intensity of solar radiation on the absorber. Distributed concentrating collectors can be classified as one-axis and two-axis tracking systems. Although the theoretical concentration limits for one-axis tracking systems can reach 215, in reality single-axis tracking systems on the market have concentration ratios from 10 to 60. As a result, one-axis tracking collectors are capable of producing temperatures up to ca. 300 C (572 F). Solar collectors for energy to be delivered above 300 C (572 F) must be able to track the sun about two axes. The performance of one-axis trackers (parabolic troughs) is generally evaluated in one of three specific configurations: east-west, north-south, and polar.

In an east-west layout, the absorber tube is oriented east-west and tracks the sun as it moves in a north-south direction. In a north-south configuration, the absorber tube is oriented north-south and tracks the sun as it moves from east to west each day. In a polar mount, the absorber tube is oriented north-south and tilted up from the horizontal by the latitude angle.

The polar-mounted collectors generate the highest amount of energy annually, primarily because losses of incident energy are kept to a minimum. The north-south horizontal trough produces less annual energy than the polar-mounted collector, and the east-west horizontal orientation produces the least annual energy of the three configurations. Generally, the east-west trough produces more uniform output annually than the north-south trough orientation, while capital costs and design difficulties preclude the use of polar-mounted collectors.

INDUSTRIAL THERMAL ENERGY DEMAND
The demand for process heat is enormous — ca. 20% of total US energy consumption. Of this demand, some 80% is now provided by premium fuels (oil and gas). This process heat is used in many applications over a very wide temperature range; 25, 50 and 70% of process heat is required at temperatures less than or equal to 200, 500 and 1000 F (93, 260 and 538 C), respectively. Throughout this range of temperatures, there are solar thermal systems that can operate effectively.

Some of the considerations for the selection and matching of solar thermal systems to applications are:
  - the temperature level of the process heat and the temperature tolerance imposed on the required process heat;
  - thermal energy demand as a function of time;
  - the response characteristics of the backup energy systems to fluctuating loads imposed by variations in available solar energy; and
  - the location of the project and the local climate.

Obviously, the best application for a solar thermal system is one which can accommodate all the solar energy that can be collected in a location where the insolation is high.

One group of industries particularly suited for the application of solar energy is the Food and Kindred Products Group (US Department of Commerce, Standard Industrial Group 20). This group of industries requires thermal energies at temperatures well below 400 F (204 C). In 1974 they consumed 319 x 10^{12} Btu (3.36 x 10^{17} J). Of this, ca. 11% was consumed by soybean oil mills, animals and marine fats, and shortening and cooking-oil industries in a temperature range between 160 and 350 F (71 and 177 C). In this temperature range, concentrating collectors can find many applications should economic incentives be available.

PARABOLIC TROUGH COLLECTOR SYSTEMS
In the past several years, much effort has gone into the
The disadvantages of water as a heat-transfer fluid are, of course, its high vapor pressure under the design operating conditions for this system and its potential for freezing. Although both these concerns can be dealt with, operation of such a system may not be economical in locations that experience prolonged, cold winter weather.

The parabolic trough collectors have a silvered glass parabolic surface that reflects and concentrates the sunlight upon a receiver tube through which pressurized water is circulated. Silvered glass offers the best performance of all mirror surfaces — its specular reflectance is high and it is easy to clean and maintain. The receiver tube, surrounded by an annular glass tube, is coated with black chrome for fairly high surface absorptivity, very low emissivity, and thus enhanced collection efficiency. A vacuum is maintained in the space between the receiver the glass tubes to minimize conductive and convective heat losses from the receiver tube.

In our solar thermal system, the collectors are 120 ft (36 m) long with an aperture (mirror rim-to-rim distance) of 10 ft (3.05 m). The dimensions and layout represent the results of a series of trade-off studies of such factors as end losses; wind loads and the ability of the mirrors to focus accurately; and the cost of manifolds, collector controls and pumping.

With the parabolic trough collectors, both the receiver tube and collector mirror rotate to keep the sun’s reflected image focused upon the receiver tube. Accordingly, the connection between the receiver tubes and the manifolds conveying the water to and from the collectors must also rotate. To accomplish this, we use a flexible hose that also accommodates thermal expansion in the receiver tubes and manifolds.

The remainder of the system is simple, consisting of a pressurized-water circulation pump, a steam generator, an accumulator, an instrument air compressor, motor control gear and an instrument panel. To enhance the performance and reliability of the system, we have made no attempt to control the temperature of the water as it emerges from the collector field. Rather, the pressurized water is circulated at a constant rate; therefore, should insolation (intensity of sunlight) decline, then so also do the water exit temperature and heat losses. By this means, solar energy is collected as efficiently as possible without the possibility of water temperature and pressure excursions as a result of inadequate or failed temperature controls.

Earlier, we mentioned that this solar thermal system is modular. We have achieved this modularity in our detailed design and in our fabrication and installation plans by minimizing both the site-specific design work required and the amount of field work. In particular, the pump, vessels, instrument air compressor, control panel and instrumentation are prefabricated, shop-mounted upon a skid, and tested before shipping. Similarly, the pipes and rotary connections are prefabricated, piece marked and tested prior to shipping. By this means, site work is limited to site preparation, the pouring of foundations, the erection of the collectors, the bolting together of prefabricated pipes, the insulation of pipes off the skid, the hooking up of power supplies, the laying of control and power cables between the collector field and the skid and the connection of the solar thermal system to the plant. Field welding is limited to the joining of 20 ft (6.1 m) sections of receiver tube, the welding of adjustment pieces joining the flexible hoses to the receiver tubes, and the welding of pipe supports.

Following installation and start-up of the solar thermal system, unattended operation should be possible. Routine maintenance of such a facility is expected to be limited to the lubrication of the collector drives and the cleaning of

FIG. 1. Schematic of solar thermal system.