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Solar Industrial Process Heat Markets for Central Receiver Technology

J. D. Fish

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SOLAR INDUSTRIAL PROCESS HEAT MARKETS FOR CENTRAL RECEIVER TECHNOLOGY

Jim D. Fish
Large Power Systems Division
Solar Programs Department
Sandia National Laboratories, Livermore

ABSTRACT

Although the emphasis of the Solar Central Receiver Program over the past few years has been electrical generation for utilities, there is renewed interest in the role for central receiver technology within the industrial sector for process heat applications. Process heat accounts for approximately one half of industrial energy usage and for approximately one sixth of the total U. S. energy usage. Based on a synthesis of the available information concerning industrial process heat markets, it is concluded that only two types of central receiver systems need be developed to have significant impact on industry: 1) systems producing saturated steam up to 550°F, and 2) systems delivering air up to 1200-1500°F. Applications amenable to near-term penetration are identified for both types of systems. Finally, a number of program elements to define the specific characteristics of the two systems are presented.

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SOLAR INDUSTRIAL PROCESS HEAT MARKETS FOR CENTRAL RECEIVER TECHNOLOGY

Introduction

Within the DOE Solar Central Receiver Program a sound technology base has been developed for electrical generation. Conceptual designs have been developed for commercial scale systems based on several different receiver heat transfer fluids. A concurrent effort of individual component development and testing has been carried out in support of the system designs. Construction has begun on the 10 MWe Pilot Plant near Barstow, which will represent the first complete system demonstration of grid connected solar thermal electric conversion in the United States. Confidence in the application of central receiver systems to electricity generation is such that DOE, designers and manufacturers of the equipment, and potential users are beginning to talk of near-term commercialization of the technology.

Recognizing that the central receiver technology developed to date can be used for any application for which temperature and fluid requirements can be met, two questions arise:

1. Which other applications are best suited for central receiver technology?

and

2. Are there areas where modest additional development of technology can greatly increase the potential market for the central receiver concept?

Two broad classes of applications on which current interest is focused are applications within industrial process heat (IPH) markets and applications related to the generation of fuels and energy intensive chemicals. This report addresses only the first class of applications. The latter class of applications will be discussed in a separate report.

General Market Considerations

At least three studies [1,2,3] have analyzed industrial energy usage in the United States and the role that solar technologies might play in displacing some of this energy. As a result of a number of factors including different data bases and different approaches, the details of the studies vary considerably. The major conclusions, however, are quite consistent. The actual numbers used below are best estimates based upon these studies, analyses of other data, and personal contacts. It should be noted that ±50% accuracy is the best that can be justified by the data.

As shown in Figure 1, industrial energy consumption accounts for over a third of the present U. S. total of approximately 80 x 10^{15} BTU/YR (80 QUADS). The industrial usage is broken down further in Figure 2. Of the 29 QUADS, various fuels with a combined heating value equivalent to 5 QUADS are actually consumed as feedstocks, 12 QUADS are consumed in generating the electricity used by industry, and 12 QUADS are consumed as process heat.

The magnitude of these numbers is best given perspective by calculating the amount of solar hardware represented. A central solar plant of the size considered commercially attractive for electrical applications would produce energy at the rate of $\sim$1 x 10^9 BTU/hr (300 MW_t). To supply one QUAD per year would require 450 of these plants operating 8 hours per day. From another point of view, it would take approximately 5 million heliostats (49 m^2 each) to produce one QUAD per year. The land area required for this number of heliostats would be $\sim$250,000 acres. InterTechnology [2], assuming an expanding economy, estimated that the total potential for solar process heat in industry in the year 2000 is approximately 13 QUADS. A capture of even 10% of this potential market by solar would be substantial.

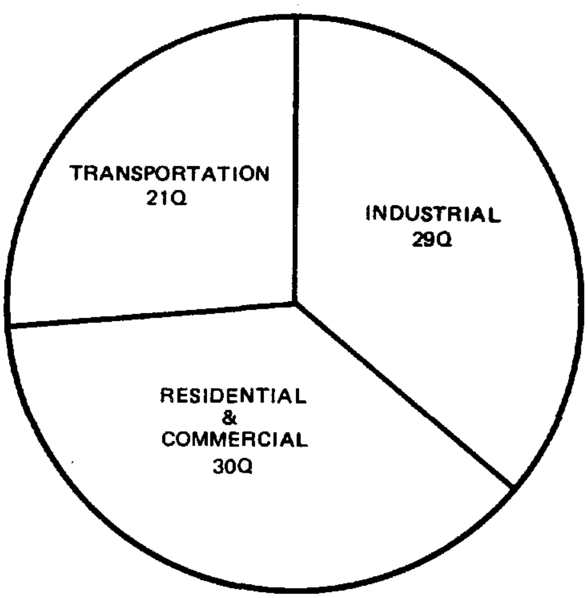

Figure 1. Total Energy Use (80 QUADS)

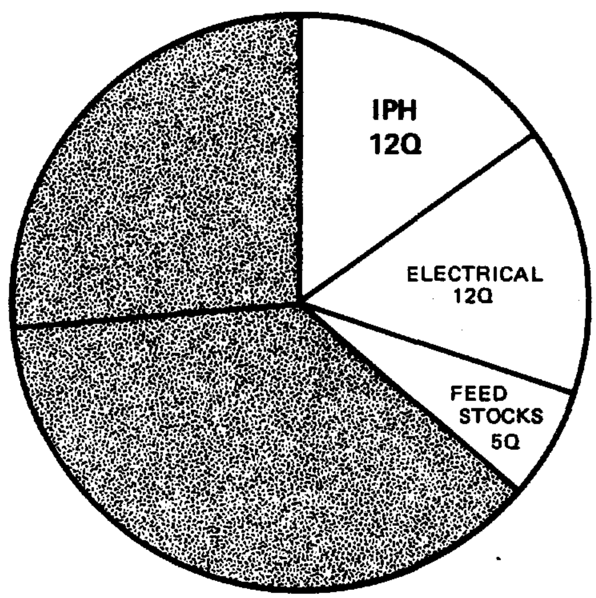

Figure 2. Breakdown of Industrial Energy Consumption

Specific Market Considerations

In Figure 3, process heat usage is divided into two general modes of delivery. The section labeled "steam" includes processes heated with saturated steam as well as those heated with hot water. For either case, interface with a water/steam central receiver system would be straightforward. The section labeled "hot air" includes: 1) processes actually using hot air (e.g.) crop drying); 2) processes in which the process fluids are heated directly in fossil-fired kilns and furnaces; and 3) processes heated indirectly via heat exchange with a heat transfer medium. The third general mode of delivering energy to a process is electrical heating. The energy consumed in generating the electricity used by industry in this manner has been included in the section labeled "electrical" in Figure 2.

All of the non-electrical methods of heating a process currently have in common the combustion of a fuel on site. The differences are only in the manner by which energy is delivered to the process. For the non-steam applications, the most straightforward approach would be interface solar technology with the combustion equipment. For example, an air receiver system preheating combustion air to 1000°F would reduce the amount of fuel burned for a given heat load by 20% if only stoichiometric quantities of air were required and by greater than 20% if excess air is used. For processes actually using hot air, the solar system could provide much larger fractions of the demand by incorporating storage with the combustion equipment serving in back-up function only. A significant advantage of the combustion air preheat approach is that it offers the potential for solar technology to impact higher temperature markets without the necessity for the development of receivers operating at the process temperatures. This matter is discussed further in the section below on markets for hot air systems.

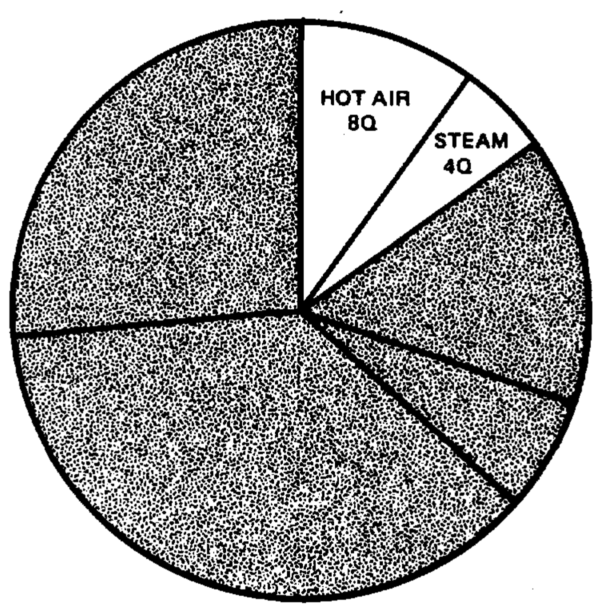

Figure 3. Breakdown of IPH

Steam--The breakdown of steam usage by temperature is 1 QUAD below 212°F (hot water), 2 QUADS between 212°F and 350°F, and 1 QUAD between 350°F and 550°F [1, 2, 4]. The pulp and paper industry and petroleum refineries are the two largest identified steam users, with the former accounting for over a QUAD and the latter for approximately half a QUAD. Other industries in which steam usage is large are food, textiles, chemical, and primary metals.

The potential for solar energy in oil refineries has been examined in detail by SERI [5,6]. They identify that portion of refinery process heat needs supplied by steam at less than 550°F as a viable application for solar technology. Approximately 25% of refinery process heat requirements is covered by this portion (0.5 out of a total of 2.0 QUADS). For a Gulf coast location with a solar plant designed for full process steam load at peak solar and no storage, the solar displacement of energy would amount to 16.3% of the total solar potential (as identified above), or 4.1% of the total refinery process heat load. For a 100,000 barrel per day refinery, the solar plant would occupy approximately 240 acres. SERI's assessment is that this area is not out of line with land currently vacant at refineries.

Although the estimated solar contribution only amounts to 4.1% of the total refinery process heat load, on an industry-wide basis this represents almost 0.1 QUAD, or a potential market for ~500,000 heliostats. Furthermore, this market is only the beginning, the best segment for near-term penetration of a larger market.

Hot Air--Specifically identified [1,2,6,7,8] non-steam process heat markets are shown in Figure 4. Petroleum refineries account for more than 98% of the non-steam markets below ~1200°F and for a significant fraction of the market in the 1500 - 2000°F range. Essentially all of this heat is supplied by fossil-fired process heaters in which the process materials are heated directly. These heaters range in capacity from 10 to 800 x 10^6 BTU/hr [6]. In some cases, primarily for safety reasons, heating of a petroleum process is accomplished via an intermediate loop of heat transfer oil. The latter type of heating, discussed in more detail below in the section on the retrofit contracts, may be ideally suited for solar. Since the heater is remote from the process, interface problems are minimized. The total market for systems based on oil receivers, however, appears to be less than the markets for systems based on water/steam and air receivers.

Lime calcining accounts for another large fraction of the IPH market in the 1500 - 2000°F range. Calcination is a mine-mouth operation in which limestone is heated to drive off CO_2. Rotary kilns are the most common type of equipment for calcination (~85% of the total U. S. production [2]). Vertical kilns and fluidized bed kilns are also used. Capacities of 150 - 250 ton per day are typical of all three types. Although half of the lime plants in the U. S. have only one kiln, the bulk of lime production comes from large, multiple-kiln plants. In 1974, the nine largest plants produced 27% of the total production averaging 650,000 ton per year each. The next 33 plants produced between 200,000 and 400,000 ton per year each. Newer kilns equipped with energy recovery units use from 4.0 to 6.5 x 10^6 BTU per ton lime produced. The requirements are as high as 14 x 10^6 BTU per ton for older units. Aerospace Corporation has identified the lime industry as a good candidate for solar applications [7,8].

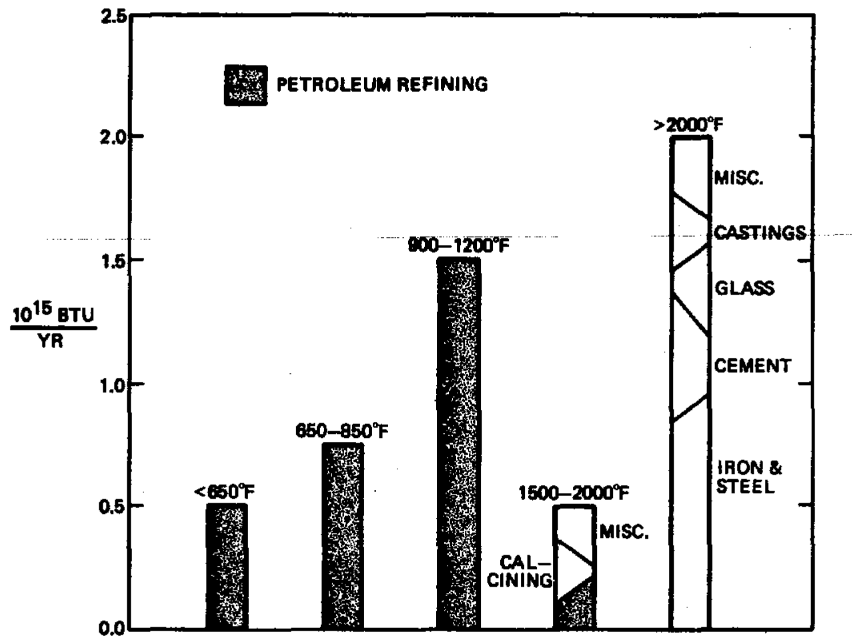

Figure 4. Potential Markets for Hot Air Systems

Development of very high temperature solar receiver systems (> 2000°F) has been suggested for application to the high temperature processes indicated in Figure 4 as well as those high temperature processes currently heated electrically. Electrical heating is common practice in both steel and glass manufacturing. Advantages for electrical heating over direct firing include ease of control, flexibility, and in some cases, better economy (as a result of the relative price of electricity and alternate fuels, and of reduced heat losses with internal heating). Processes such as direct fixation of nitrogen in a plasma arc represent another fairly common application of electrical heating. Interfacing solar technology with any of these high temperature (2700 - 4000°F) processes would require major process adaptation as well as significant breakthrough in solar receiver design to reduce cost and increase efficiency [9].

The iron and steel industry and glass manufacturing also are major consumers of non-electric energy at very high temperatures (>2000°F). Due to process details and industrial practices, much of this energy is consumed in such a manner that direct substitution with solar-derived energy would be difficult--even if an efficient and cost effective very high temperature receiver (> 2700°F) were developed. For example, much of the high temperature heat demand for the iron and steel industry is supplied as a by-product of the reduction reaction between iron ore and coke. The reaction itself is highly exothermic. In addition, the blast furnace off-gas is a low grade fuel for which on-site burning is the best use. Within the cement industry, reaction rates, heat transfer considerations, and the effects of transients would make substitution of solar derived energy difficult and expensive. With any of the high temperature processes, major process modifications would be required for direct solar heating. These applications, however, do represent a substantial market for lower temperature solar technology directly for preheating of the combustion air and fuel used in the primary process and indirectly for associated lower temperature processes.

On-going IPH Studies

Currently, under the U. S. Department of Energy Solar Repowering/Industrial Retrofit Program [10], six site-specific solar IPH conceptual designs are being developed. These contracts will provide detailed technical information with respect to interfacing central receivers and industrial processes. In addition, economic evaluations of the projects are being carried out independently by each industrial partner.

The proposed systems span the large general markets discussed above. Three of the systems are based on water/steam receivers. The other three systems are based on a hot air receiver, an oil receiver, and a receiver reactor.

One of the water/steam systems addresses the large steam market within oil refineries. The system would generate high pressure saturated steam ($\sim$500°F) for a new Provident Energy Company refinery under construction at Mobile, Arizona.

Another water/steam system addresses a steam market that could become quite significant. The system would replace the combustion of oil for generation of steam used for thermal enhanced oil recovery in Exxon's Edison Field near Bakersfield, California. This system also produces high pressure saturated steam ($\sim$550°F).

The final water/steam system would produce saturated steam at 360°F for uranium ore processing at the Gulf Mt. Taylor Uranium Mill, currently under construction near San Mateo, New Mexico.

The hot air system is being designed to displace natural gas burned for drying wall board at the U. S. Gypsum Plant near Sweetwater, Texas. At the design point, receiver exit temperature would be $\sim$1250°F. After expansion through a turbine, which drives the air circulators and a small generator, the air would be delivered to the wall board kiln at 900°F. The receiver exit piping interfaces directly with the external combustor of the gas turbine where natural gas firing maintains a turbine inlet temperature of 1250°F regardless of the level of solar insolation. The advantages of this approach include a uniform air temperature to the board kiln and ease of hybridization and control. The generality of preheated combustion air for a variety of industrial applications was mentioned above.

Heat transfer oil would be heated directly in the central receiver system being designed for the ARCO gas processing plant near Bakersfield, California. Existing natural gas fired heaters would maintain the required process temperature of 580°F. As with the hot air system above, the hybridization approach lends significance to the oil receiver system beyond the specific application under consideration.

The final system involves a tower mounted solar reformer in which methane would react with steam to produce hydrogen for Valley Nitrogen Producers' Ammonia plant near El Centro, California. This system will be discussed in more detail in a separate report on solar fuels and chemicals.

Programmatic Implications

Based on market considerations (and confirmed by the industrial response to the Repowering/Industrial Retrofit Program solicitation), it appears that the most promising IPH applications for central receiver technology involve delivery of process steam or hot air.

It remains to be determined which central receiver technologies best satisfy these potential markets (both technically and economically). For example, can solar technology based on air receivers supply the demand for hot air more cost-effectively than sodium or salt receivers coupled to the process through a heat exchanger? Sandia Laboratories has started this assessment with a comparison of the U. S. Gypsum hot air receiver system described above with a salt receiver system for the same application. Additional comparisons of the other retrofit designs with systems based on other receiver types and comparisons of a more general nature will follow.

Of particular interest is the appropriate role of storage for solar IPH applications. Almost all industrial processes operate at steady state for long periods of time ranging from days to months. For such processes, a solar system without storage could provide no more than ~25% of the energy requirement on an annual basis. In the near-term, this 25% would represent a significant amount of solar equipment. In the far-term, however, larger solar fractions must be considered, and the interplay between storage and fossil hybridization addressed.

Also of interest is the range of temperatures for which hot air receivers should be developed. For combustion air preheat applications, displacement of primary fuel increases with receiver exit temperature. The cost of the receiver, however, increases; and the efficiency decreases with increasing temperature. The same trends apply with respect to cost and efficiency of storage. Thus, there is an optimum operating temperature for a given application. This optimum temperature may also depend on the amount of storage capacity required.

In parallel with the technology related questions, there are many unknowns with respect to the economic environment within the industrial sector and the constraints this environment may place on solar penetration of the market. Sandia Laboratories has also started addressing these considerations. Preliminary indications are that segments of the industrial markets may have economic barriers to solar technology comparable to or even less stringent than the electric utility market. For example, enhanced oil recovery appears to be a viable near-term application for solar thermal systems. In this case, solar energy would be competing directly with oil. Furthermore, the current tertiary oil recovery incentive program provides for accelerated recovery of a large fraction of the capital invested in solar equipment.

Summary

The potential IPH market for solar technology is large, and opportunities for near-term penetration of the market appear to exist. The attractiveness of the market and the industrial interest as expressed by the Repowering/Retrofit Program both justify significant IPH-related efforts within the Solar Central Receiver Program. The efforts, however, can be bounded--only two types of central receiver systems need be developed to have significant impact on industry: 1) systems producing saturated steam, and 2) systems delivering hot air. Some of the questions concerning the specific characteristics of these systems are discussed in the previous section. Studies to answer these questions and to identify further questions have begun at Sandia. The efforts carried out over the past few years under the Solar Central Receiver Program provide an excellent basis from which to proceed.

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