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Issue Brief

Solar Thermal Energy for Industrial Uses

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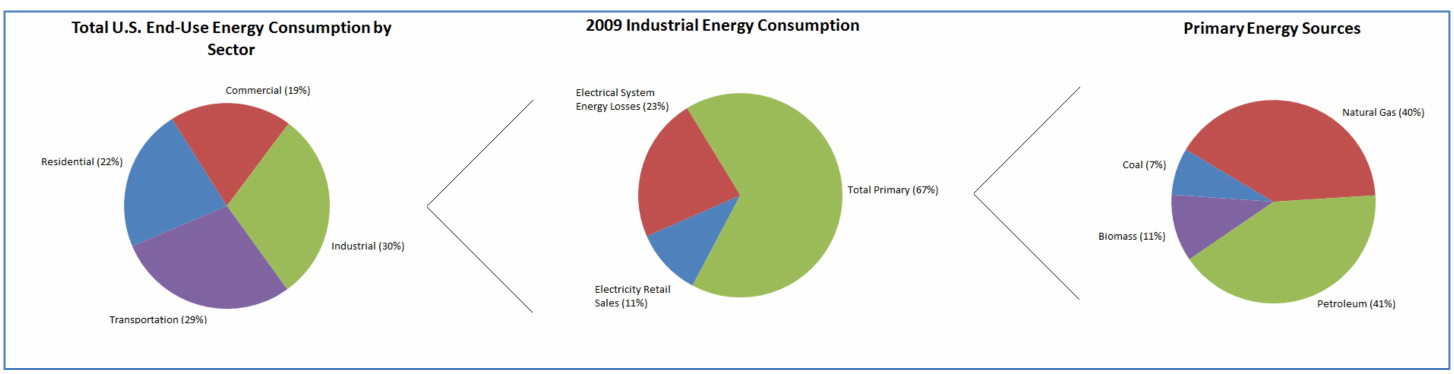
INTRODUCTION

Heat is often underappreciated in public policy discussions on energy, frequently overshadowed by transportation energy and electric power. However, heat accounts for 37 percent of energy consumed within most developed countries, and 47 percent of the world's energy consumption.[1] While many people associate solar energy with electricity-producing photovoltaic (PV) panels, solar can also be used for heating purposes. Solar thermal energy is most commonly used to heat outdoor swimming pools and residential water in the United States, but it can also be used for many types of industrial processes.[2] This issue brief will examine the role that solar thermal technology currently plays in industrial heating processes and outline opportunities for increased application within the U.S. industrial sector.

The industrial sector is the leading source of energy consumption in the United States. At nearly one third of total energy use, it exceeds both the transportation and residential sectors.[3] Within the industrial sector, nearly two thirds of energy used is consumed as heat. Some industries have even higher rates, such as the glass industry, which consumes about 80 percent of its energy for heating purposes.[4] The remaining third can be attributed to electricity generation or energy lost in transmission within the grid, or by inefficient conversion within the power plant itself.[5]



Source: IEA, 2009.

Depending on how industrial thermal energy is defined, nearly 90 percent of the energy comes from burning fossil fuels, but biomass can count for up to 11 percent.[6] The remaining 10 percent of thermal industrial energy comes from electricity, which is often generated by power plants that burn fossil fuels. When including the environmental degradation from extracting fossil fuels, like mountaintop removal mining, water pollution from hydraulic fracturing of shale for natural gas, the air pollution emitted after their combustion, and large emissions of greenhouse gases, there is a clear social incentive to find alternative sources of energy. Industry's role as the largest consumer of energy in the nation, its large heat requirements, and its heavy reliance on fossil fuels, present tremendous opportunity for application of solar thermal technology.

SOLAR: ELECTRICITY OR THERMAL

Solar thermal collectors and solar PV panels comprise the two main types of solar energy. PV panels convert solar radiation into electricity, whereas solar thermal collectors convert the sun's rays directly into usable heat. Once the collector converts the sun's rays into heat, that heat can be used for a variety of purposes spanning all sectors of industry.

Solar energy is converted to electricity and heat at different rates. Solar conversion efficiency is the ratio of energy produced from the panel or the collector to the energy content of the sunlight itself. Solar thermal conversion efficiency is approximately 70 percent compared to PV panels, which converts light to electricity at roughly 17 percent efficiency.[7] Despite a high conversion rate and wide-ranging application, solar thermal energy is virtually absent from the industrial sector. According to the International Energy Agency (IEA), solar thermal energy is a practical technology with much room for innovation which has been largely unexploited for industrial needs.[8] As of 2008, there were only 90 solar thermal plants for industrial process heating worldwide, comprising a combined 25 thermal megawatts (MW_{th}) of output. When compared to the 118 GW_{th} of solar output worldwide, this constitutes less than 0.02% of total solar thermal capacity.[9] As of 2011, there are fewer than 100 documented applications.[10]

CHARACTERISTICS OF INDUSTRIAL THERMAL DEMAND

Industrial heating needs can be categorized into three main temperature ranges. All of them can be achieved with solar. The lowest temperature range consists of everything below 80°C. Solar collectors are capable of meeting these temperatures and are commercially available today.[11, 12] The medium temperature category is between 80°C and 250°C. While the collectors servicing this level of heat demand are relatively limited, they do exist and are on the verge of emerging into competitive commercial production.[13] The highest range includes everything over 250°C and requires concentrated solar power (CSP) (see appendix) to achieve such temperatures. While CSP furnaces are rare—a few have been installed in the United States for electricity production[14]—they can achieve temperatures as high as 3500°C.[15,16]

Many industries already can take advantage of the commercially available low and mid-range temperature solar thermal collectors. They are particularly suited to meet the heating needs of the food, beverage, textiles, paper and pulp industries. Processes like sterilizing, pasteurizing, drying, hydrolyzing, distillation and evaporation, washing and cleaning, and polymerization do not require high temperatures and can easily benefit from flat plate and evacuated tube collectors (see appendix, table below).[17] According to a study of industrial heating in European countries, **30 percent of industrial processing requires heat below 100°C and 27 percent of industrial heating needs can be met with heat between 100-400°C, and 43 percent requires heat over 400°C**.[18] In the food, wine and beverage, transport equipment, textile, machinery, and pulp and paper industries, roughly 60 percent of the heating requirements can be met by temperatures below 250°C.[19] Despite tremendous opportunity, solar thermal heating for industrial processes has been insignificant compared to the residential sector, and the few industrial applications that do exist have been experimental in nature.[20]

In 2005, the IEA's Solar Heating and Cooling (SHC) Program published a survey of existing technologies and identified research opportunities for improvements in efficiency and effectiveness. One objective of the program was to bridge the gap between the large potential for solar heating at medium temperatures, and the low commercial availability of appropriate solar collectors. While collectors capable of reaching 250°C are not yet commercially available, some researchers have indicated that the necessary improvements have been achieved and that the technology need only be scaled up for large scale application.[21]

INDUSTRY	PROCESS	TEMPERATURE(°C)
Dairy	Pressurization	60-80
	Sterilization	100-120
	Drying	120-180
	Concentrates	60-80
	Boiler feed water	60-90
Tinned food	Sterilization	110-120
	Pasteurization	60-80
	Cooking	70-90
	Bleaching	70-90
Textile	Bleaching, dyeing	60-90
	Drying, degreasing	100-130
	Dyeing	70-90
	Fixing	160-180
	Pressing	80-100
Paper	Cooking, drying	60-80
	Boiler feed water	60-90
	Bleaching	130-150
Chemical	Soaps	200-260
	Synthetic rubber	150-200
	Processing heat	120-180
	Pre-heating water	60-90
Meat	Washing, sterilization	60-90
	Cooking	90-100
Beverages	Washing, sterilization	60-80
	Pasteurization	60-70
Flours and by-products	Sterilization	60-80
Timber by-products	Thermo diffusion beams	80-100
	Drying	60-100
	Pre-heating water	60-90
	Preparation pulp	120-170
Bricks and blocks	Curing	60-140
Plastics	Preparation	120-140
	Distillation	140-150
	Separation	200-220
	Extension	140-160
	Drying	180-200
	Blending	120-140

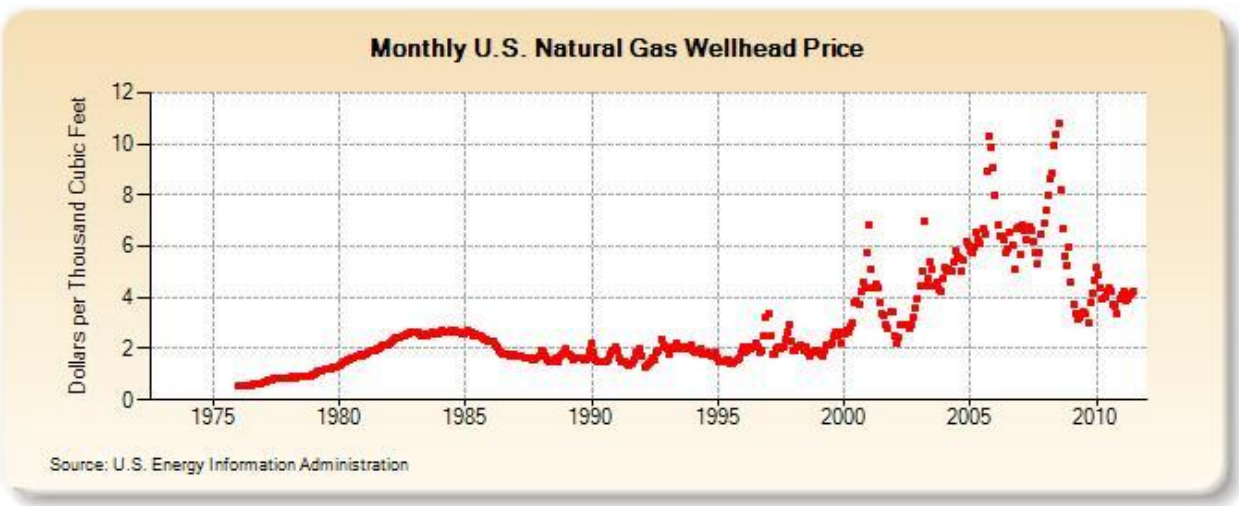
Source: Mekhilef *et al.*, 2011[22]

BARRIERS

Despite the large potential for solar energy to meet industrial thermal demand, there are several barriers to large scale implementation. The most noteworthy barriers are cost, variability of output, energy storage and process integration.

Cost

The economic viability of solar thermal energy depends largely on two factors: the initial cost of the installation and the price of alternatives.[23] High upfront costs often prevent companies from investing in new technology, like solar thermal, even if the overall lifetime cost would be lower. However, while the cost of solar technologies is decreasing, the financial investment in solar remains more stable than many of the markets for fossil fuels. Thus, the largest driver of a collector's cost effectiveness is often the price of alternatives, like coal, oil and natural gas, not the cost of the collector itself.[24] The more expensive fossil fuels become, the easier it is to justify an investment in solar thermal energy. Nevertheless, if the price of solar thermal were to drop, it would certainly enhance its economic viability. With the volatility of fuel prices, some manufacturers opt for the fixed upfront cost (see case studies) with a predictable payback period. In addition to the potential for a lower overall cost, there exists a benefit from having a predictable cost structure which is insulated from fuel market volatility. Approximately 40 percent of industrial primary energy comes from natural gas, and approximately 41 percent comes from petroleum,[25] two of the most price-volatile energy sources available.



Source: IEA, 2011.[26]

Source: IEA, 2011.[27]

Furthermore, solar thermal collectors can be made even more cost effective when tailored to the specific process heating needs of the plant (see Process Integration below). On the factory level, large-scale applications can benefit from economies of scale and lowered investment costs, increasing its economic viability.[28] On the national level, the IEA estimates that costs can be reduced by as much as 20 percent when a country's total installed capacity doubles.[29]

Variability

Solar energy, like wind energy, can be predicted to a high degree of confidence. Its availability, however, presents challenges for industries that require "24/7" demand. The reliability of the heating supply is of paramount concern to many manufacturers for whom an unanticipated disruption in production can be economically devastating. Solar thermal energy is reliable but not always available. Therefore, industries which either do not require constant production, or for whom the sunlight availability can be aligned with heating requirements, may be more confident about integrating solar thermal energy into their production. The variability of sunlight can also be mitigated by conducting statistical analyses of heating requirements vis-à-vis the regional insolation—the irradiance per square meter over a given period of time. This can be conducted as part of a procedure known as process integration (see below). Another possible solution is to store heat for later use to smooth the gaps in sunlight availability (see below).

Process Integration

Process integration, also known as "pinch analysis," is a field of engineering which seeks to optimize operational energy efficiency, or in other words, to reliably produce a product with the minimum energy inputs necessary. The variability of energy supply must be quantified based on daily solar radiation, ambient temperature profiles, and available storage opportunities, so that the solar collectors can be optimized to reduce economic inefficiencies.[30] Variable energy, like solar and wind, presents a particular challenge for process integration because the supply of energy is non-continuous.[31] Therefore, the nature of solar thermal energy supply must be addressed or it can become unaffordable in some cases.

If solar collectors supply all of the energy, the manufacturer must either align production with the energy supplied, or store the energy for later use. However, even if sunlight is not available to meet all of a factory's thermal energy needs, solar thermal can still play a role by supplying a portion of the total energy required. Under such hybrid systems, solar collectors can provide a baseline energy supply whenever it is available and the remainder can be fulfilled by a complementary fuel source. **The commercially available low temperature collectors are especially effective in this strategy and are often used for pre-heating purposes**.

Energy Storage Options

Large scale thermal energy storage is a nascent market but it can compensate for the inherent variability of sunlight. For low and medium temperatures, this can usually be performed by storing the heat in a transfer fluid like hot water or oil. Sometimes pressurized steam is used. For higher temperatures, this becomes more difficult, and costly, and requires an alternative heat transfer fluid and storage material.

The most common heat transfer fluid for CSP is **molten nitrate salt**, which is thermally stable within a temperature range of 220° C to 565°C, below which the salt freezes.[32] The molten-salt system is currently the only practical thermal energy system with hours-long storage potential, and has proven reliable at commercial scales.[33] The National Renewable Energy Laboratory (NREL) has called on researchers to develop a heat transfer fluid that can sustain temperatures up to 1300°C and operate as low as 0°C.[34] This temperature, according to NREL, is a necessary component in reaching the full potential of solar thermal applications.

MARKET TRENDS

The solar thermal industry has seen steady growth over the last few years. The global solar thermal market grew by 17 percent in 2007 and again by an estimated 42 percent in 2008, largely due to a 45-50 percent surge in the U.S. residential sector.[35] By the end of 2009, the United States and Canada combined for 8.7 percent of the world-wide installed capacity.[36] China led the global market with 58.9 percent of installed capacity, followed by Europe with 18.9 percent.[37]

Excluding solar that is used mainly to heat outdoor swimming pools, the United States ranked 10th in the world in 2009 for overall installed capacity and 36th in the world for per capita capacity.[38] Firms have begun using solar thermal for industrial process heating with a few large-scale projects in Europe and China but it still remains effectively absent in the United States.[39]

CURRENT POLICIES

Established in 2010, the SunShot Initiative is a collaborative effort spearheaded by the Department of Energy (DOE) with a mission to reduce the cost of solar energy 75 percent by 2020. DOE hopes to achieve this by advancing technology, reducing grid integration costs and accelerating nationwide deployment. However, the goals specifically target PV and CSP technologies. While CSP technology can be used to achieve the higher temperature ranges needed for industrial application, the SunShot Initiative makes no effort to directly target this sector. Instead, the vast majority of CSP technology is used for utility-scale electricity production.

There are dozens of other state and federal initiatives—and hundreds more municipal and utility initiatives—but there is no large-scale effort to incentivize solar energy specifically for industrial heating. While many initiatives could be applied to industrial purposes, the specific provisions largely focus on PV panels, domestic solar water heating systems, and CSP technology for utility-scale electricity production.

CASE STUDIES

Gatorade Manufacturing Facility (Arizona)[40]

In June 2008, Gatorade, under its parent company PepsiCo, announced plans to install solar thermal water heaters on the roof of their manufacturing facility in Tolleson, Arizona. Gatorade hired Austrian solar manufacturer S.O.L.I.D. GmbH, and their U.S. subsidiary, S.O.L.I.D USA, to install a total of 85 flat plate collectors covering a combined surface area of 893 m^2 (9,605 ft^2). The collectors were installed in just three months, and went into operation on December 31, 2008. Gatorade now uses the system to preheat water to a temperature of 35°C (95°F). While the collectors have the capacity to produce temperatures above 35°C, Gatorade does not need hotter temperatures. In fact, the system actually includes a safety mechanism to ensure this never happens because it would damage the reverse osmosis equipment used to purify the water.

Solar thermal water heaters on the roof of the Gatorade Manufacturing Facility in AZ.

Photo courtesy of Gatorade

Steinway and Sons Piano Company (New York)[41]

in 2009, Steinway and Sons, a piano maker located in Long Island City, New York, hired Spanish solar manufacturer Abgenoa to install 38 parabolic trough collectors on their factory roof. The system is capable of heating water to 200°C (392°F). The piano manufacturing process requires consistent temperature and humidity as well as steam for production purposes. The piano company uses the solar collectors to boil water to 200°C, which runs an adsorption chiller to cool and dehumidify the air in the summer time. In the winter, the steam is used for heating and for production purposes.

The total project cost was $870,000, but Steinway and Sons received a $588,000 grant from the New York State Energy Research and Development Authority (NYSERDA).[42] It also hopes to receive $266,000 in federal tax credits. With annual energy costs of $2 million[43], and annual energy savings of 15 to 25 percent, the company is expecting a payback period of 4.5 years.

Hofmühl Brewery (Germany)[44, 45]

The Hofmühl Brewery in Eichstätt, Germany, installed 735m^2 (7,911 ft^2) vacuum tube collectors with parabolic reflectors on its roof. The system is capable of heating water to 100°C, and has two 55m^3 storage tanks. The brewing process does not require constant production, so the company takes advantage of the sun's availability by brewing only when the sun is shining. The brewery also uses a series of cascading heat exchangers to transport the heat throughout the brewing process. The water is heated to 90 °C and used to clean glass bottles. When the heat is between 60°C and 90°C, it is then used for brewing and to heat domestic hot water. If necessary, the heat between 45°C and 65°C is used for space heating. The remaining heat is stored within the two storage tanks, which are capable of storing hot water collected over a weekend to be used during the brewing process the following week. On days when temperatures of only 50°C to 80°C can be attained, the collectors are used for space heating only.

For comparison, Eichstätt, Germany receives approximately 1300kW/m^2 of annual solar irradiation[46], while U.S. states like Michigan, Wisconsin or New York receive over 1400kW/m^2 of annual solar irradiation.[47]

These vacuum tube collectors are used to heat water used for the brewing process at the Hofmühl Brewery in Eichstätt, Germany.

Photo courtesy of © Krones AG Neutraubling / Hofmühl- Brauerei Eich

Schulte Painting Center (Germany)[48,49,50]

The Schulte painting center in Meppen, Germany—which receives even less sunlight than Eichstätt with close to 1100 kW/m^2 of annual solar irradiation[51]—uses a combination of oil and solar energy to meet their heating needs. The process of painting and drying requires specific air temperatures. Schulte uses 137 m^2 (1,474 ft^2) vacuum tube collectors to run boilers which heat a constant ambient air flow to temperatures of 24°C for the painting chamber and 70°C for the drying chamber. The company previously used 30,000 liters (7,925 gallons) of heating oil annually and expects to cut that amount by 30 percent using the newly installed solar thermal technology. While Schulte is an environmentally-conscious company—it is the first paint shop to use water-based paint—the decision to incorporate solar technology was economically driven. Fuel prices are unpredictable and have become increasingly expensive over the past few years. The energy savings from reduced oil consumption will be used to finance the project. With an estimated 30 percent savings, Schulte expects a payback period of 7-9 years, depending on the price of oil.

ENERGY EFFICIENCY
According to the DOE's Office of Energy Efficiency and Renewable Energy, best practices in process heating, such as opportunities for heat recovery, can reduce the cost and consumption of energy by as much as 30 percent. Even plants and factories with energy management systems can improve energy efficiency from 10 percent to 15 percent by implementing best practices, thereby reducing energy costs for process heating from 5 percent to 15 percent.

- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program. January

CONCLUSION

While solar thermal use in home water heating is still extremely small, solar thermal use in other sectors of the economy is even smaller, especially in the United States. These technologies are capable of cost-effective integration into many commercial and industrial processess. However, they remain too risky for many businesses and major manufacturers due to the large upfront costs, concerns over availability of heat, and to a lack of understanding of the opportunities it provides. Despite the industrial sector consuming the largest amount of energy in the United States, and the tremendous opportunity which solar thermal technology presents, it has been largely overlooked by both manufacturers and policymakers.

Solar thermal technology is commercially available to meet demand in lower temperature ranges and already can be integrated into the food, beverage, textiles, paper, and pulp industries on a large-scale. Many of the technological barriers can be eliminated through prudent analysis of energy requirements and appropriate mechanisms for energy storage. Solar thermal's opportunity should be viewed as a way to substantially offset fossil-fueled thermal energy. A total replacement of thermal capacity could be appropriate in certain circumstances, for processes that do not require round-the-clock supply, for example, or when integration of energy storage technology to meet longer periods of demand is possible. Solar thermal integration strategies would be even more effective when coupled with energy efficiency strategies.

Incentives should do more to target the industrial heating sector specifically, and expand commercialization of medium temperature collectors and higher temperature storage technology. The economic opportunities are abundant and the environmental payoff will be much larger if policymakers focus more attention on the opportunities to reduce fossil fuel consumption in industry.

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The Environmental and Energy Study Institute (EESI) is a non-profit organization founded in 1984 by a bipartisan Congressional caucus dedicated to finding innovative environmental and energy solutions. EESI works to protect the climate and ensure a healthy, secure, and sustainable future for America through policymaker education, coalition building, and policy development in the areas of energy efficiency, renewable energy, agriculture, forestry, transportation, buildings, and urban planning. EESI is funded primarily by foundations and other private donors.

APPENDIX

Types of Solar Thermal Technology

There are two main types of solar thermal technology: stationary and concentrating (typically non-stationary). Stationary collectors do not move and can be further subdivided into flat-plate collectors and evacuated tube collectors. Stationary collectors are cheaper and require little maintenance but they can only achieve low to medium temperatures. Alternatively, concentrated solar power (CSP) collectors usually rotate to track the sun's rays and can therefore achieve much higher temperatures. However, they are also more expensive and require more maintenance.

Flat plate collectors

Flat plate collectors are simple, inexpensive and require little maintenance.[52] Most commonly used to heat outdoor swimming pools and home water heating, they consist of an insulated metal box with a glass covering and an absorber plate inside. The absorber plate utilizes the sun's radiation to warm an internal heat transfer fluid (HTF), usually water, oil or air.

Flat plate collectors can be either glazed or unglazed. Unglazed collectors have no insulation over the glass which augments both heat gain and heat loss. These collectors typically reach temperatures of only 30^{o}C are almost exclusively used to heat outdoor swimming pools. [53] Glazed collectors have an insulated glass covering and can typically achieve temperatures of up to 80^{o}C and are thus applicable to a number of the industrial heating processes in the chart above. Flat plate collectors can penetrate the medium range and achieve temperatures between 90 ^{o}C and 150 ^{o}C, but they are not yet economically efficient beyond 80 ^{o}C.[54]

Evacuated tube collectors

Evacuated tube collectors are the other stationary collector and they typically consist of a row of parallel tubes which use the sun's rays to heat an absorber plate at the center of a vacuum. These collectors can achieve higher temperatures because the vacuum reduces conductive heat loss and eliminates convective heat loss. However, they are also more expensive to manufacture. Vacuum collectors have reached economically efficient temperatures between 90 ^{o}C and 150 ^{o}C, making them a useful complement to the flat plate collectors.[55] By adding reflector plates to concentrate the sunlight, these collectors have efficiently reached temperatures up to 200 ^{o}C.[56]

Concentrating Solar Power (CSP) collectors

CSP collectors can achieve the highest temperatures but they are also the most expensive to manufacture and maintain. They are extremely rare for industrial process heating and virtually nonexistent the United States, outside of utility-scale solar power plants. CSP collectors can reach extremely high temperature by rotating to follow the sun and by using arrays of reflectors to focus large amounts of sunlight onto the absorber.

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