A new series on energy innovation

Solar Thermal Energy

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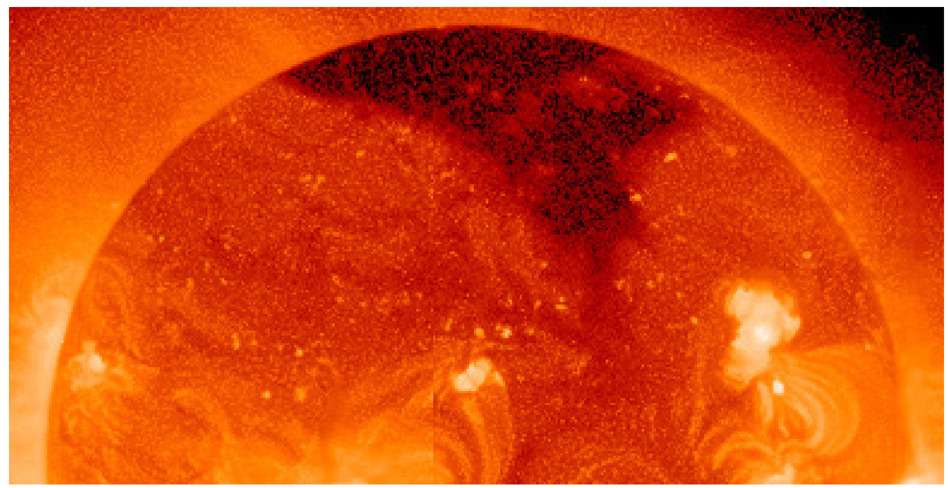
"Let the sunshine in! A renewable source for industrial processes"

Inside

Solar thermal energy (STE) refers to heat generated by solar radiation. This energy is used in industrial, commercial, and residential applications, through different technologies, including steam production, heating and cooling systems, and even electricity generation. It can produce temperatures that go from 45°C to more than 300°C, which makes it potentially useful to a broad range of sectors, such as food and beverage; textile manufacturing; chemical production; pulp and paper; and mining.



Source: Solar Insurance & Finance (Solarif)

At the end of 2010, the installed capacity of solar thermal power worldwide was approximately 195 GWth[1] (through a total installed area of 279 million m^2), compared to 282 GWe[2] for wind, 10.7 GWe for geothermal, and 40 GWe for solar photovoltaic (PV). Today, the majority of the solar thermal installations provide energy to households to heat water. Still, the current installed capacity represents only 0.4 percent of global hot

1 Gigawatt thermal or thermal gigawatt (GWt or GWth) refers to thermal power produced.
2 Gigawatt electrical (GWe) is a term that refers to electric power.

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water demand in the residential sector. In terms of the industrial sector, the use of STE accounts for less than 100MWth[3] of worldwide capacity; the growth potential for STE is significant in both these sectors.

The growth potential of STE seems even more robust when one considers the drive to increase the use of renewable energy and the sustainability of the global and country level energy matrix. According to the International Energy Agency (IEA), STE could provide the industrial sector with 3 to 4 percent of its total heat demand (Figure 1) and up to 20 percent of the total global industrial demand for low temperature heat by 2050 (Figure 2). The potential use for STE around the world is considerable, particularly in Latin America (Figure 3).

[3] Total installed capacity has been estimated by the author, taking into account data provided in past publications and projects built as of today.

Figure 1. IEA Roadmap: Vision for Solar Industrial Heat in Relation to Total Final Energy Use for Low Temperature Industrial Process Heat

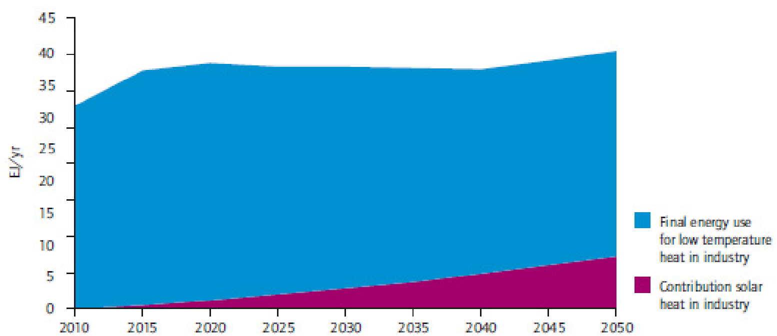


Figure 2. IEA Roadmap: Vision for Solar Heating and Cooling

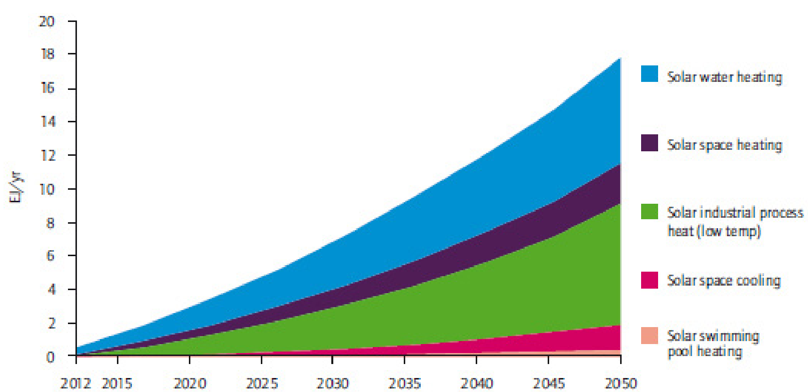
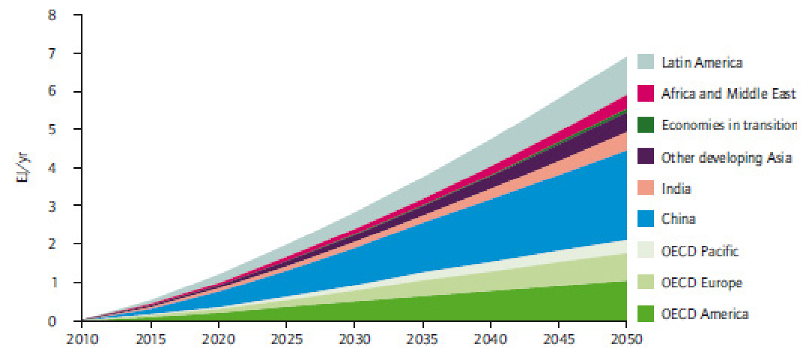


Figure 3. IEA Roadmap: Potential for Solar Thermal Industrial Process Heat



Source: "Technology Roadmap: Solar Heating and Cooling," IEA 2012.
Note: 1 Exajoule = 277 TWh.

Solutions Provided by Technology

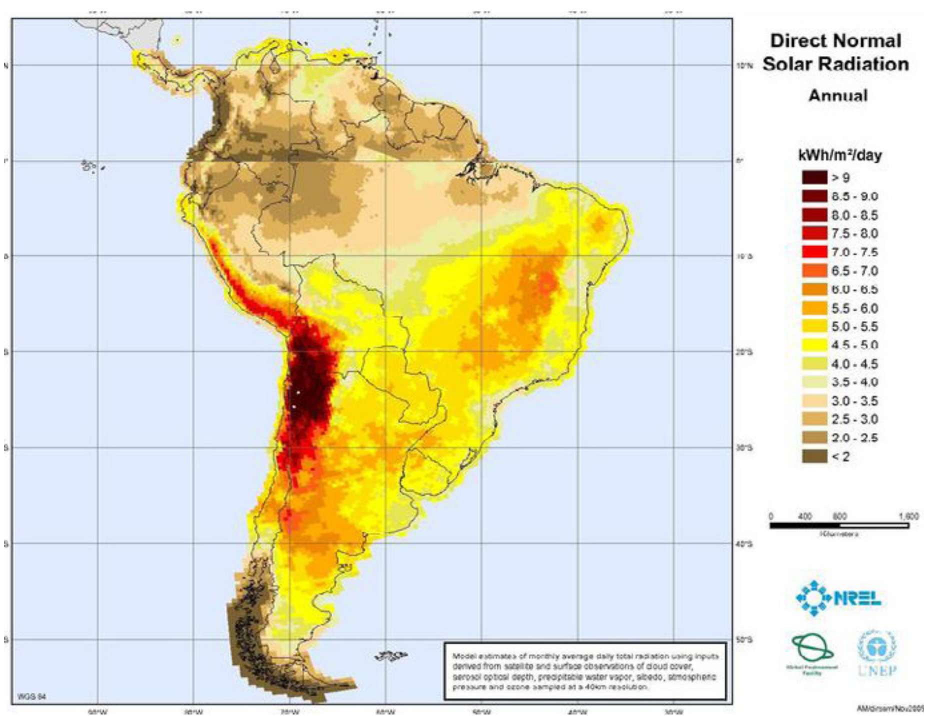
The use of STE in industrial processes significantly reduces the direct consumption of primary energy sources.[4] It also provides energy at a predictable and stable price, as most of the installation costs are covered with the initial investment. For other sources, the cost depends on variable, and often volatile, fuel or electricity prices. Further, the environmental impact and CO_2 emissions of STE are extremely low, which contributes to increasing sustainable energy production and mitigating climate change.

[4] **Primary energy** is a natural nonrenewable or renewable energy form that has not been subject to any conversion or transformation process. It is energy contained in raw fuels and other forms of energy received as input to a system.

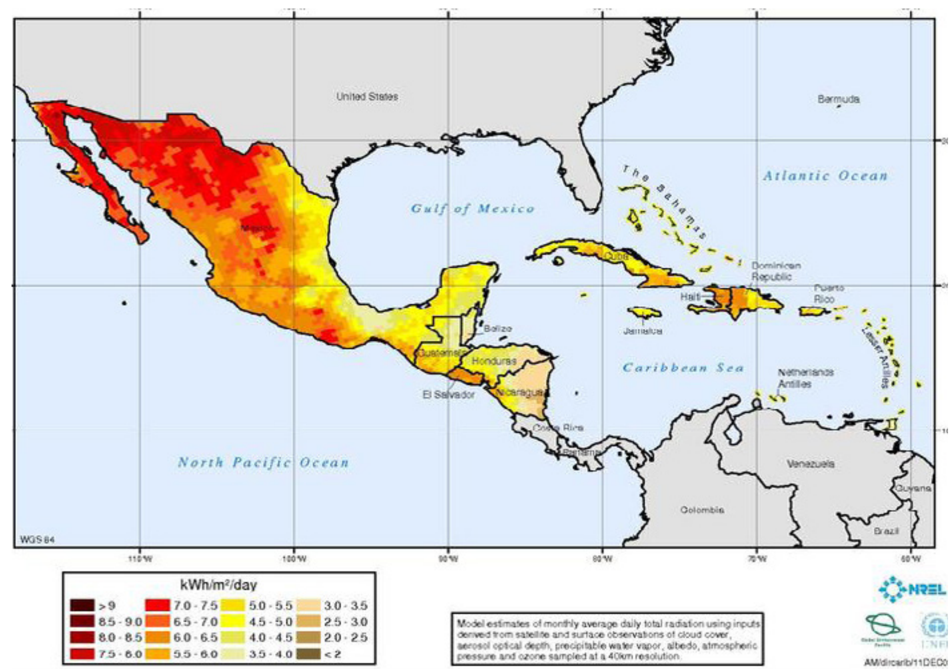
Best Locations to Implement Solar Thermal Energy Projects

As is the case for any renewable energy source, the availability of the natural resource (in this case, solar radiation) is paramount to determine whether or not it is a viable energy generation solution. In general terms, the locations with the greatest potential for STE use are those with an annual Global Horizontal Irradiance (GHI)[5] above 2,500kWh/m². As the maps below demonstrate, in the Latin American and Caribbean (LAC) region, the Atacama Desert in Chile and its surroundings (i.e., the Altiplano Plateau/ Puna de Atacama in Argentina and Chile, the Norte Chico in Chile, and the Sechura Desert in Peru), western Brazil, and northern Mexico (the states of Baja California, Durango, Chihuahua, and Sonora) are well suited to use this technology.

Direct Normal Solar Radiation – Annual



Direct Normal Solar Radiation – Annual



[5] **Global Horizontal Irradiance (GHI)** is the total amount of shortwave radiation received from above by a surface that is horizontal to the ground. Photovoltaic modules and flat collectors for heat production can harness the total GHI received. GHI includes both **Direct Normal Irradiance (DNI)**, a solar radiation that comes in a straight line from the direction of the sun at its current position; and **Diffuse Horizontal Irradiance (DHI)**, a solar radiation that comes from all directions, as it has been scattered by molecules and particles in the atmosphere.

Key Challenges

Along with the abundance and predictability of solar radiation, the following challenges should be considered in determining the feasibility of STE use in industrial applications:

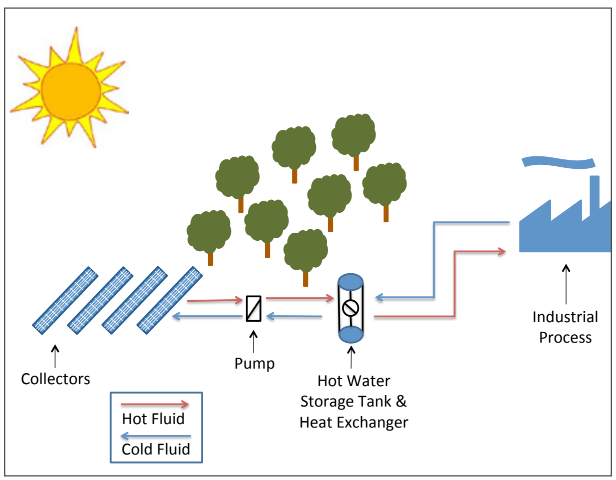
1. The comparative cost of conventional energy sources and solar thermal technology. As expected, costs vary among countries, within a particular country, and from company to company, as do the specific energy consumption levels of the companies and the negotiated contractual agreements.
2. The temperature level required in the specific industrial process. Processes that demand low and medium temperatures are the most cost efficient.
3. The heat requirements (on an annual, weekly, and daily basis) for different processes and temperature levels. Energy generation can be maximized through an analysis of hours, days, and months with the highest solar radiation. Although storage is available, it increases the overall cost and, hence, is not always economically viable.
4. The possibility to connect with available conventional heat supply units. This may be needed to back the solar installation in case of low solar radiation and lack of storage.
5. Availability of great fluid volumes (existing storage tanks, steam vessels, liquid baths, etc.). Fluids should be maintained to avoid the need for additional storage.
6. Space availability to install the solar collectors and, better yet, the possibility to integrate the installation into existing industrial buildings.
7. Public policies supporting the implementation of the technology in the industrial sector.

Source: eLlaima/Sunmark.

The Technology

Solar thermal collectors convert the solar radiation directly into heat. Installation consists of the following:

- A solar collector field through which water alone, or a combination of water and glycol, is circulated (primary circuit)
- A regulation system to control any mismatch between the heat requirements and the varying solar radiation intensity
- A heat exchanger that supports the regulation system and transfers the heat from the collectors' fluid to the fluid used in the industrial process (normally steam or hot water)
- A conventional heat supply system, if necessary



Source: Author's elaboration.

Types of Collectors

Industrial processes usually require thermal energy within a range of temperatures from ambient levels to more than 250°C. The required temperature range determines the type of solar collector to be used and the way it will be integrated into the preexisting industrial heating system. Solar collector efficiency decreases as the temperature of the fluid used in the process (e.g., water, glycol, oil, etc.) increases, or as the available solar radiation decreases.

Stationary Collectors

These collectors are mounted and do not use any mechanisms to track the sun. Heat produced by these collectors reaches low and medium temperatures of up to 150°C. The most developed stationary collectors are the following:

Flat Plate Collector (FPC)

Alsp-solar

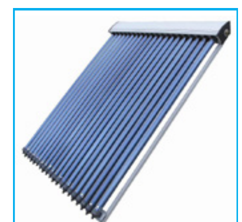
An FPC is the simplest form to transform solar energy into heat. The fluid circulating in the absorber is mainly water, which is often mixed with additives (e.g., glycol) to avoid freezing. However, other liquids can be used depending on the application, particularly based on the required operating temperature. To control heat losses, the FPC can incorporate different types of coatings, which are designed to have the highest possible radiation absorption.

Evacuated Tube Collector

Source: Authors' image

An evacuated tube collector is composed of multiple evacuated glass tubes containing an absorber plate fused to a heat pipe. The heat from the hot end of the pipe is transferred to the transfer fluid (water or glycol) of a hot water or hydronic space heating system via a "manifold," which is wrapped in insulation and covered by sheet metal or a plastic case to protect it from the elements. The vacuum that surrounds the outside of the tube greatly reduces convection and conduction heat loss, which makes it more efficient than the FPC, particularly in colder conditions. This advantage is largely lost in warmer climates, except in those cases where very hot water is required.

Compound Parabolic Collector (CPC)



Clearchain

A CPC is formed by two parabolic surfaces with the same focus. An absorbing tube is fixed at the focus to transport the solar energy received by the surface of the tube as heat. The CPC concentrates the solar radiation onto the focus and can also receive diffuse radiation depending on the accepting angle. Although this feature allows the collector to produce heat even during a cloudy day, the absorbing surface is limited to the cylindrical surface of the tubes.

Non-stationary Collectors

Unlike stationary collectors, non-stationary collectors use mechanisms to track the sun. Heat produced by these collectors reaches medium and high temperatures of up to 300°C. The most common non-stationary collectors used for industrial processes are the following:

Parabolic trough collector

NJIT

The parabolic trough collector has a single axis and is used in both solar process heat plants and large power plants. Reflectors with a parabolic shape concentrate the direct solar radiation onto the receptor—which consists of an absorber tube of an area usually 25 to 35 times smaller than the aperture—located in the focal line of the parabola. The heating fluids, typically water and thermal oil, are circulated through the absorber piping. The low thermal loss coefficient makes this collector efficient for applications that need higher temperatures. Contrary to stationary collectors, parabolic troughs cannot use the Diffuse Horizontal Irradiance (DHI); however, due to their sun tracking mechanism, they are more efficient in making use of the Direct Normal Irradiance (DNI).

Fresnel collector

The linear concentrating Fresnel collector is formed by an array of mirror strips that are uniaxially tracked, which allows them to reflect the DNI onto a stationary thermal receiver. The receiver uses an absorber tube with a secondary concentrator. Although this type of collector was developed for large-scale solar thermal power generation, it can be scaled down for the generation of solar industrial process heat. The Fresnel collector is easily mounted on flat roofs, offering good weight distribution and low wind resistance. With this setup, the collectors take up little ground space and are concentrated in areas closer to the demand.

Source: Linear Fresnel Collector. CIEMAT, Spain

Thermal Heat Storage

Once the most efficient solar collector has been chosen, the next step is to determine the need for a facility to store the heat. This decision is application-specific, and is determined by the consumption curve and the economic feasibility, considering the increase in cost incurred by adding the storage.

Industrial Solar Systems without Storage

In many industries, the demand for heat is higher than the expected STE supply, so there is no need for storage. The simplest case would be a continuous operation line with a heat demand that is higher than the solar gains during most operating hours (i.e., for at least 12 hours per day during the daytime). In this case the solar heat produced is fed directly to the industrial process or to the heat supply system.

Industrial Solar Systems with Heat Storage

If the industrial process is idling for one or more days, such as over the weekends, the system can be designed to store the energy collected for later use. Storage may also be necessary if there are strong fluctuations in the heat demand during operating hours. Heat can be stored in water for low temperatures and in molten salts for high temperatures. Storage can also be used to help address variability of the solar resource (increased plant factor) and to provide a constant heat supply, allowing the use of STE at times without solar radiation (i.e., nighttime, limited time cloud coverage).

Industrial Applications

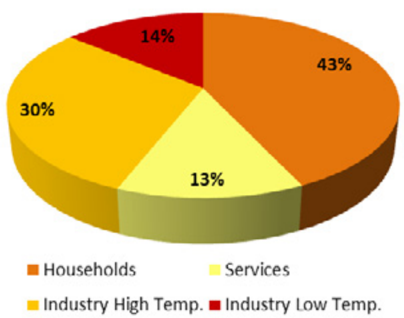
According to a study carried out by the Euroheat & Power,[6] industrial applications account for 44 percent of the total heat demand in a sample of 32 countries. Further, more than 50 percent of the industrial heat demands in the industrial sector range from low (<60°C), to medium (60°C–150°C), to medium-high (150°C–250°C) temperatures, which emphasizes the potential for this technology.

[6] **Euroheat & Power** is an organization that unites the combined heat and power/ district heating and cooling sector throughout Europe and beyond, with members from over 30 countries, including all existing national district heating associations in EU countries and the majority of new EU Member States, utilities operating district heating systems, industrial associations and companies, manufacturers, research institutes, consultants, and other organizations involved in the combined heat and power/ district heating and cooling sector.

Industrial Heat Demand by Temperature Range and Sector

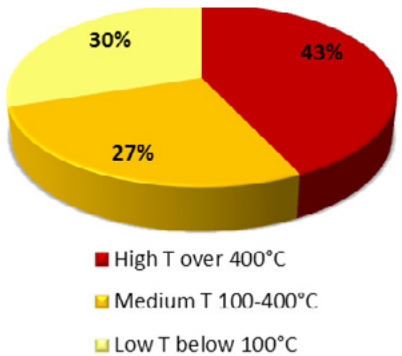
Although current data on the breakdown of heat demand in the industrial sector by different temperature ranges is not exhaustive in the LAC region, Euroheat & Power has established that 30 percent of the industrial heat demand in a sample of 32 countries is required at temperatures below 100°C and 57 percent at temperatures below 400°C. Moreover, important sectors—such as food and tobacco; transport equipment and machinery; textiles; and pulp and paper—that demand heat between low and medium temperatures (below 250°C) account for approximately 60 percent of the total demand. That said, the pulp and paper sector primarily uses heat recovery systems and, therefore—even though the theoretical potential demand for STE is high—in most cases, it would not be economic to add a solar thermal plant to the process.

Figure 4: Heat Demand by Sector, 2003



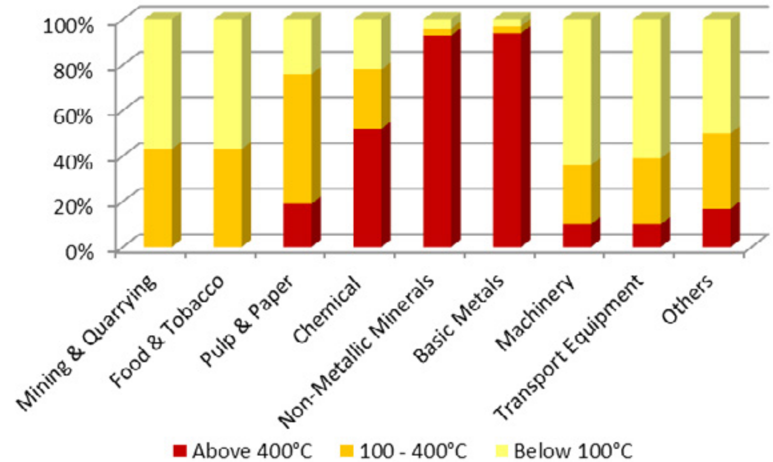
Source: "Ecoheatcool Work Package 1: The European Heat Market," Euroheat & Power, 2003.
Note: 32 countries: EU25 + Bulgaria, Croatia, Iceland, Norway, Romania, Switzerland, and Turkey.

Figure 5: Share of Heat Demand in the Industrial Sector by Temperature Level, 2003



Source: "Ecoheatcool Work Package 1: The European Heat Market," Euroheat & Power, 2003.
Note: 32 countries: EU25 + Bulgaria, Croatia, Iceland, Norway, Romania, Switzerland, and Turkey.

Figure 6: Share of Industrial Heat Demand by Temperature Level and Industrial Sector



Source: "Ecoheatcool Work Package 1: The European Heat Market," Euroheat & Power, 2003.
Note: 32 countries: EU25 + Bulgaria, Croatia, Iceland, Norway, Romania, Switzerland, and Turkey.

The actual temperature required by the process is the key component of the feasibility of using this technology in the industrial sector.

Although the potential for the application of solar thermal technology within a specific industrial sector can vary substantially from one location to another, those sectors with the highest potential are food and beverage; textile; transport equipment; metal and plastic treatment; chemicals; and copper mining. The most suitable industrial processes in these sectors include cleaning, drying, evaporation and distillation, blanching, pasteurization, sterilization, cooking, melting, painting, surface treatment, solvent extraction and electro-winning, and space heating and cooling of factory buildings. The relevance of each sector with regards to further market development also depends on the local industrial profile.

Key Global Projects

Solar District Heating System

Project Description
Capacity: 25MWth
Industry: District heating
Investment: US$24 million
Location: Riyadh, Saudi Arabia
Startup Date: June 2011
Design and Construction: Millennium Energy Industries (MEI)

This project, currently the largest of its type in operation, consists of a solar thermal plant that provides hot water and space heating for Princess Nora University's 40,000 students and staff. It is engineered to endure extreme weather—from freezing winter conditions to intense heat and sandstorms. The system collectors cover an area of 36.305m² and its collectors heat pressurized water to a temperature below 100ºC. The water is then used to feed the district heating system. A 900m³ heat storage system allows the plant to operate 24 hours a day. The project reduces CO_2 emissions by 12,500 tons per year, and through its lifetime, will substitute the equivalent of 52 million liters of diesel.

Frito-Lay Manufacturing Plant

Project Description
Capacity: 4MWth
Industry: Food
Location: Modesto, California, USA
Startup Date: July 2008
Design and Construction: Abengoa Solar

This project consist of 384 parabolic through collectors, a fully operational plant, and a steam heat exchanger that handles the collectors' 5.068m² of concentrating surface. The steam temperature reaches 250ºC, used to produce corn and potato chips. The pressure within the installation is 41bars. The backup is provided by steam generation fuelled by natural gas.

Source: Abengoa Solar.

Note: Currently, less than 100 STE plants for process and district heat are operating worldwide, with a total capacity below 100MWth. **District heating** is a system for distributing heat generated in a centralized location for residential and commercial heating requirements.

Key Projects in Latin America

Kraft Food Brazil Project

Project Description

Capacity: 350KWth

Industry: Food

Location: Recife, Brazil

Startup Date: April 2012

Design and Construction: Abengoa Solar

This project consists of an STE system that delivers heat for cooking, cleaning, drying, and pasteurizing fruit juices, cookies, and candies. The system uses concentrated parabolic trough collectors, to heat pressurized water to a temperature of 110°C. The solar field represents a total aperture area of 633m². The system can be expanded to meet the growing demand of the facility.

Source: Abengoa Solar.

Minera el Tesoro (Antofagasta Minerals) Project

Project Description

Capacity: 7MWth

Industry: Mining

Investment: US$14 million

Location: Antofagasta Region, Chile

Startup Date: November 2012

Design and Construction: Abengoa Solar

The project consists of an STE plant that delivers heat for solvent extraction and electro-winning (SX-EW) of copper cathodes in a mining facility. The system uses 1,280 concentrated parabolic trough collectors, that cover an area of 55,000m², to heat pressurized water to a temperature above 100°C. The solar field represents a total aperture area of 16,742m². A 127m³ heat storage system allows the facility to operate after dusk. The installation produces 25GWh of thermal energy a year which reduces CO_2 emissions by 10,000 tons as well as diesel consumption by 55 percent per year.

Source: Abengoa Solar.

eLlaima & Sunmark Project (Minera Gaby Codelco)

Project Description

Capacity: 32MWth

Industry: Mining

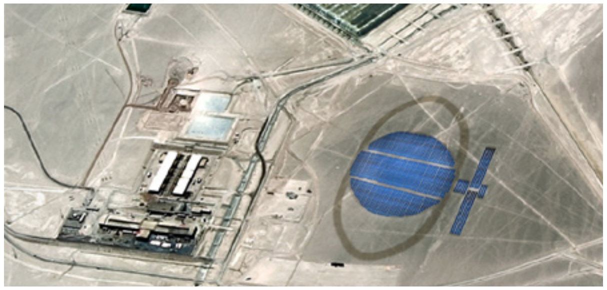
Investment: US$24 million

Location: Antofagasta Region, Chile

Estimated Startup Date: September 2013

Build, Own and Operate: eLlaima & Sunmark

The project is also owned and operated by eLlaima & Sunmark. It consists of an STE plant that delivers heat for solvent extraction and electro-winning (SX-EW) of copper cathodes in a mining facility. The system uses 2,620 flat collectors of 15m² to heat water to a temperature below 100°C.The system covers an area of 39,300m². A 4.000m³ heat storage tank backs the system, allowing it to operate 24 hours/day. The installation produces 52GWh of thermal energy per year, reducing diesel consumption by 85 percent (equivalent to a reduction of 6,500 tons of diesel per year), and CO2 emissions by 15,000 tons/year.



Source: eLlaima & Sunmark.

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Conclusions

The potential use of solar thermal energy in the industrial sector in Latin America and globally is substantial. At current market conditions STE costs are competitive to conventional energy sources. Hence, this technology is a viable substitute for hydrocarbons to generate heat for industrial processes, particularly at low and medium temperatures. Yet, in spite of significant benefits, STE is underutilized. It will take effort to revert this trend. Raising awareness of industry and governments would be a good place to start.

Additional Information on Solar Thermal Energy

English

Spanish

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This is the second issue of a new series dedicated to deliver concise information on energy innovation. The series is published by the Energy Innovation Center (EIC), an integral part of the IDB's Energy Division in the Department of Infrastructure and Environment.

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