Concentrated solar heat

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wbcsd

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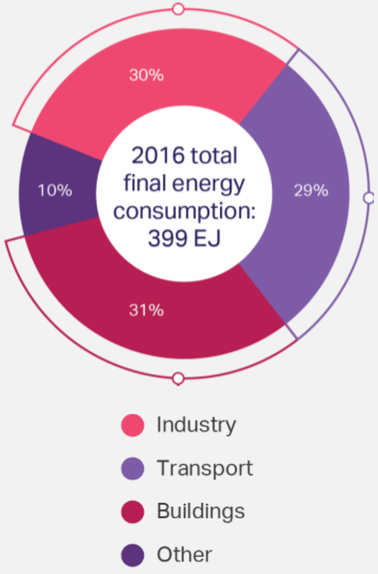
1. Background

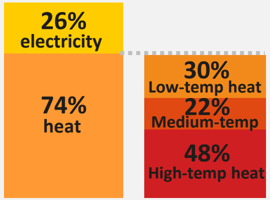
Heat represents a large share of industrial energy demand and most is met by fossil fuels

World energy demand[1]



Energy use in industry

- **Heat represents 74%** of industrial energy demand worldwide[2]
- **Half of it** is low (below 150 °C) to medium temperature heat (150-400 °C)[2]



- 90% of industrial heat demand is currently **met by fossil fuels**.[3]

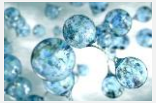
Possible solutions to decarbonize heat

- **Electric heat pumps** typically provide heat up to 100°C, with 160°C in next generation heat pumps

- **Solar radiation**

- **Bioenergy**

- **Geothermal energy**



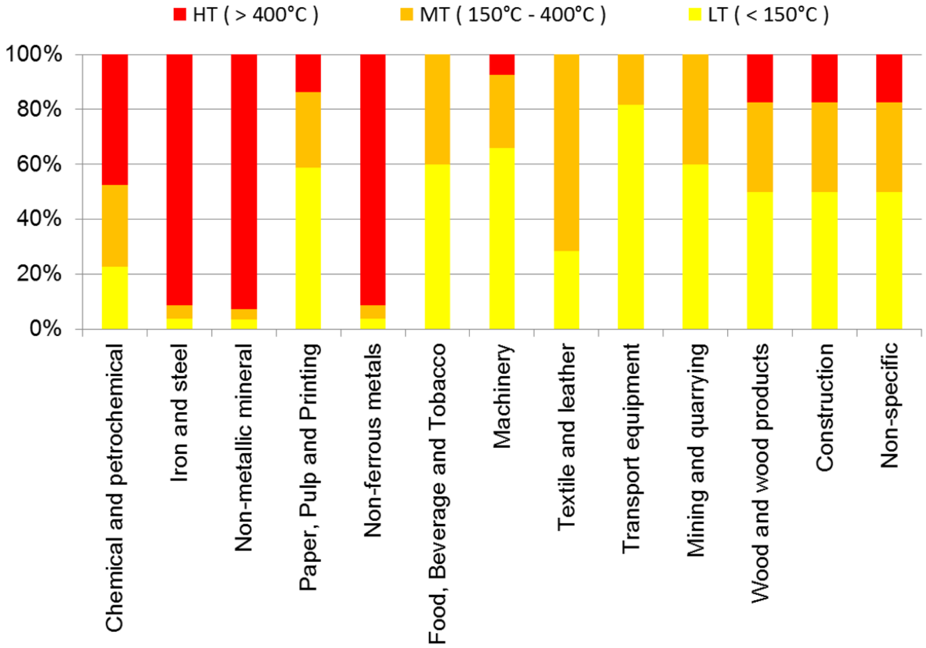
- **Combustion of hydrogen-rich synthetic fuels** (from renewables-based electrolysis of water)

- **Electricity generated from renewables** (from the grid or self-consumption)

Sources: [1] IEA, 2017: *Energy Technology Perspectives 2017*; [2] IEA, 2017: *Renewable Energy for Industry – From green energy to green materials and fuels*; [3] Solar Payback, 2017: *Solar Heat for Industry*.

1. Background

Heat temperature requirements from a selection of industrial sectors



Source: Fraunhofer ISE, 2017: *Solar Heat for Industrial Processes*.

- Many industrial processes require **heat in the low to medium temperature heat range**
- The **total heat demand for low and medium temperature applications is 44 EJ globally**[1]

Sources: [1] Solar Payback, 2017: *Solar Heat for Industry*.

1. Background

An overwhelming reliance on conventional fossil fuels for industrial heat

Current industrial heat provision and associated CO_2 emissions	• Industrial heat demand represents **22% of worldwide energy demand** and 90% of this demand is currently met by fossil fuels.[1,2] • Overall, annual direct CO_2 emissions (includes heat and process emissions) from industry amount to about 8.5 $GtCO_2$ or about **a quarter of global CO_2 emissions**.[1]
Forecasted developments in a business-as-usual scenario	• In its Reference Technology Scenario, the IEA projects that global direct CO_2 emissions from the industry sector (including energy-related emissions and CO_2 emissions from industrial processes) will grow by 24% from 2014 to 2050.[1] • In absolute terms, emissions are projected to grow to 10.4 $GtCO_2$ in 2050 under this reference scenario.[1]
Obstacles to decarbonizing this energy use	• The development of direct renewable heat in industry is hindered by barriers such as **lack of nearby land space (for solar heat)**, long distances to high-value resources (e.g. geothermal heat) and high costs (of appropriate biofuels). • Although producing hydrogen from renewable electricity could become increasingly competitive compared to fossil fuels, high technology costs means that hydrogen is not yet competitive with fossil fuels for producing heat.

Sources: [1] IEA, 2017: *Energy Technology Perspectives 2017*; [2] Solar Payback, 2017: *Solar Heat for Industry*.

2. Description of concentrated solar heat

Overview

Description of the new solution concept	• **Concentrated solar heat (CSH) turns sunlight into thermal energy**. • **Concentrated technologies** like Fresnel collectors or parabolic troughs use direct irradiance only and are geographically limited to areas with good direct normal irradiance (DNI*), i.e., clear skies and strong sunlight. • The alternating day/night profile of solar heat needs to be addressed by the integration of a thermal storage facility.
Rationale for developing this solution	• As **concentrating technologies** can reach **400°C**, they can be a **zero-carbon means of meeting medium temperature process heat needs**. • While high temperatures >400°C could also be reached, such applications are relatively novel.
Assessment of technology readiness status	• **Non-concentrating technologies prevail today** because solar heat tends to be more competitive with fossil fuels at low temperatures. • **Solar concentrating technologies** are not yet mature but are expected to develop in coming years. • **Thermal storage** is not yet proven for all applications and temperatures.

*Direct Normal Irradiance (DNI) is solar radiation that comes in a straight line from the direction of the sun at its current position in the sky. Areas of high DNI are typically hot and dry and located in latitudes between 15° to 40° north or south.

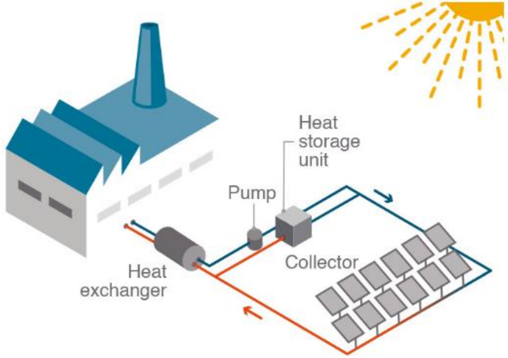
2. Description of concentrated solar heat

Capturing solar energy for heat in industrial processes

- **Solar heat for industrial processes** use a **collector** to capture solar radiation. The solar radiation heats a fluid, such as water, and a heat exchanger transfers this heat for use in industrial processes. **Heat storage and control systems** are needed for industrial facilities to handle the non-continuous supply of solar energy.

- Two groups of collector technologies can be distinguished:
  - **Non-concentrating collectors for low temperature heat (<150°C)** – such systems use conventional flat-plate collectors and evacuated tube collectors, both of which are mature technologies.
  - **Concentrated solar heat (CSH)** – concentrators use various collector shapes to concentrate sunlight onto the absorber to reach temperatures of between 150-400°C. CSH is relatively novel compared to non-concentrating systems.

- **The focus of this business case is on concentrated solar heat.**



Source: Solar Payback, 2017: *Solar Heat for Industry*.

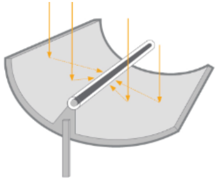
2. Description of concentrated solar heat

Capturing solar energy for heat in industrial processes

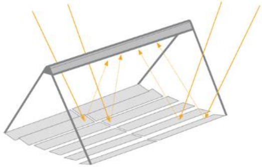
- Different CSH collectors exist:
  - **Parabolic trough collectors** concentrate the solar rays on long heat collector pipes (moving with the troughs).
  - **Linear Fresnel collectors** use slightly curved mirrors reflecting the solar rays on a long, fixed receiver.
  - **Concentrating dish collectors** concentrate the sunrays on a focal point that is moving together with the dish tracking the sun, offering the highest optical efficiency on smaller capacities.

- CSH collectors can track the sun, so that they face the sun throughout the day.

- The same technology is used in concentrated solar power (CSP) plants.



Parabolic trough collector



Linear Fresnel collector

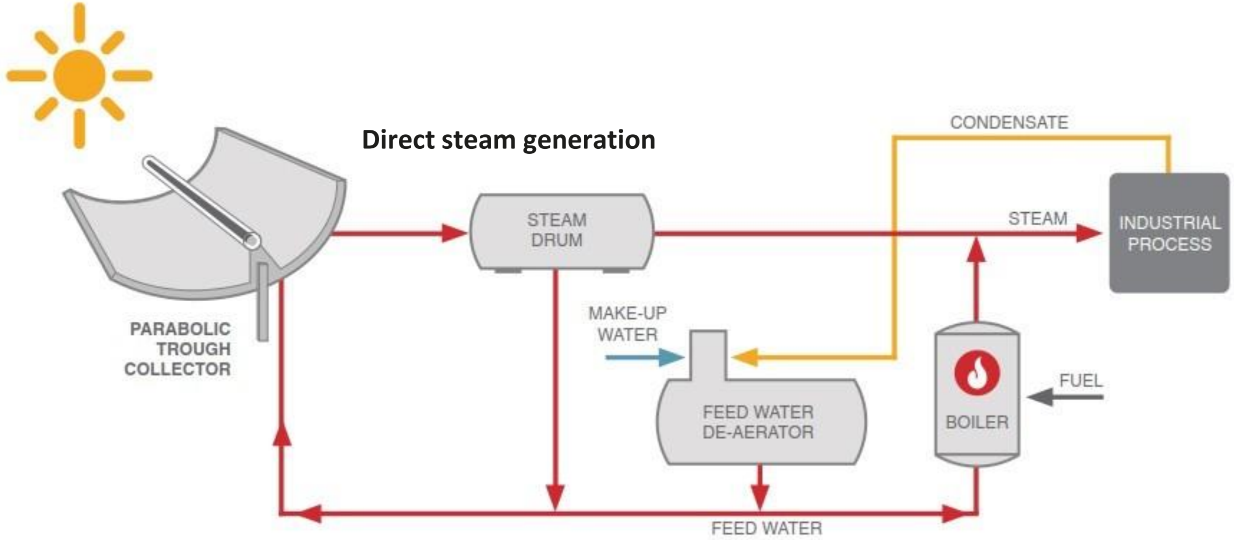
Concentrating dish collector

Source: Solar Payback, 2017: *Solar Heat for Industry*.

2. Description of concentrated solar heat

Concentrated solar heat can be used for direct or indirect steam generation

- **Direct steam generation:** Water is partly evaporated in the concentrating parabolic trough collectors. The solar-heated steam is then separated from the remaining water in the steam drum before being supplied to the industrial process or the steam network of the factory.
- **Indirect steam generation:** in this case, the collector heats water or thermal oil in a closed circuit to generate steam via a heat exchanger.

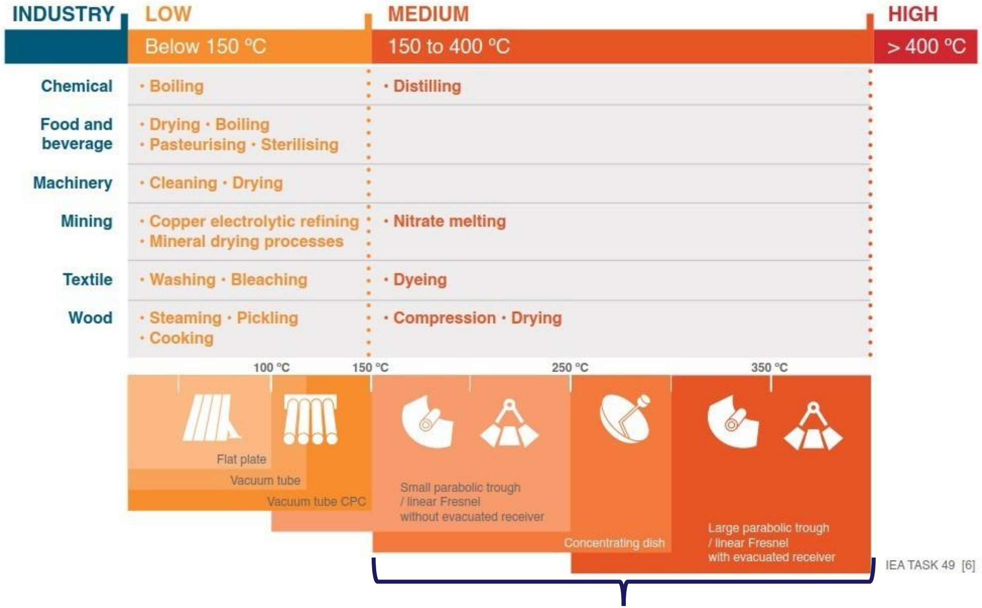


Source: Solar Payback, 2017: *Solar Heat for Industry*.

2. Description of concentrated solar heat

Technology overview: Solar collector technology vs. required process temperature

- With advanced solar process heat technologies, temperatures of 150°C up to 400°C can be provided, making it a technology suitable for medium temperature heat. Concentrated solar heat technologies can potentially fulfil 22% of industrial heat demand in the industrial sector.



Concentrating technologies

Source: Solar Payback, 2017: *Solar Heat for Industry*.

3. GHG reduction potentials of concentrated solar heat

GHG emissions assessment of current and new solution

- Solar heat has a **positive impact on the industrial user's carbon footprint as the substituted energy is often a fossil fuel** (natural gas, liquified petroleum gas, paraffin, oil, etc.).
- **Direct avoided CO_2 emissions are dependent on the substituted fossil energy source**. The following table provides estimates of the CO_2 saving potential per kWh of the compensated fossil energy source:[1]

Fossil fuel	Direct CO_2 emissions (gCO_2/kWh)
Diesel	266
LPG	227
Crude oil	263
Natural gas	205-216
Coal	319

- **From a lifecycle perspective**, solar heat's carbon footprint is about $35gCO_2eq/kWh$, which corresponds to **$210gCO_2eq/kWh$ avoided in substitution to natural gas**.[2]

Sources: [1] IFC, 2014: *Market Study of Solar Thermal Energy for Industrial / Commercial Use (Pakistan, Egypt, Morocco)*; [2] ADEME, 2018: *Intégration des énergies renouvelables et de récupération dans l'industrie*.

4. Cost assessment and sensitivity analysis

Investment costs & levelized cost of heat (LCOH)	• For **concentrated systems**, investment costs range from USD $400–1,800/kW for concentrating dish collectors; from USD $600–2,000/kW for parabolic trough collectors; and from USD $1,200–1,800/ kW for linear Fresnel collectors.[1] • The LCOH is in the range of EUR €60-90/MWh.[1]
Return on Investment (RIO) & LCOH comparison with fossil fuels	• Studies comparing the costs of CSH vs heat generated from conventional sources are scarce • The National Renewable Energy Laboratory (NREL) finds that the **LCOH for many regions in California is lower than the LCOH from natural gas**, despite historically low gas prices.[2]
Sensitivity analysis	• The LCOH is dependent on the DNI and capacity factors*. The latter is highly region-specific and can range from 16-20% (e.g. UAE/India) to 29% (e.g. Mexico).[1] • Required process temperature, project size and the need for thermal storage also affect investment costs. • Policies can also have a strong impact on the cost of CSH and its competitiveness with fossil fuels: - Carbon prices may discourage the use of fossil fuels and incentivize renewable heat options. - In many countries, fossil energy prices (such as natural gas) for industrial users are subsidized or discounted to support industrial development (e.g. Egypt). This lowers the competitiveness of CSH against fossil fuel heating technologies. - Conversely, CSH systems may benefit from **investment or heat production subsidies** in a number of countries, e.g. in France.

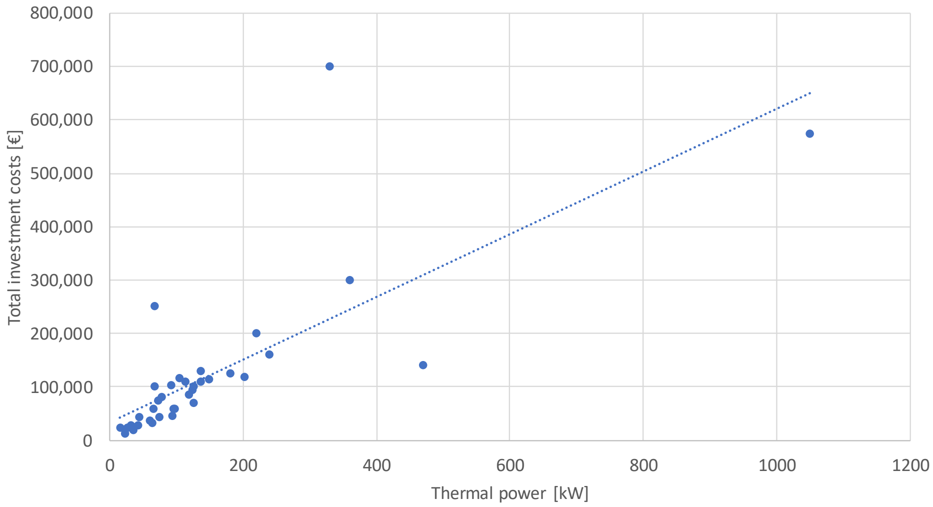
*Capacity factor: the ratio of actual output over a period of time (e.g. a year) to theoretical maximum output if a system operated at full nameplate capacity, expressed as a percentage.

Sources: [1] IRENA, 2015: *Solar Heat for Industrial Processes*; [2] NREL, 2015: *Initial Investigation into the Potential of CSP Industrial Process Heat for the Southwest United States*.

4. Cost assessment and sensitivity analysis

Market review

Investment costs for CSH projects (non-exhaustive)



- The average cost of concentrated solar heat collectors is EUR €900/kW (primarily parabolic trough collectors).

Source: AEE INTEC, 2013-2019: *Solar Thermal Plants Database*.

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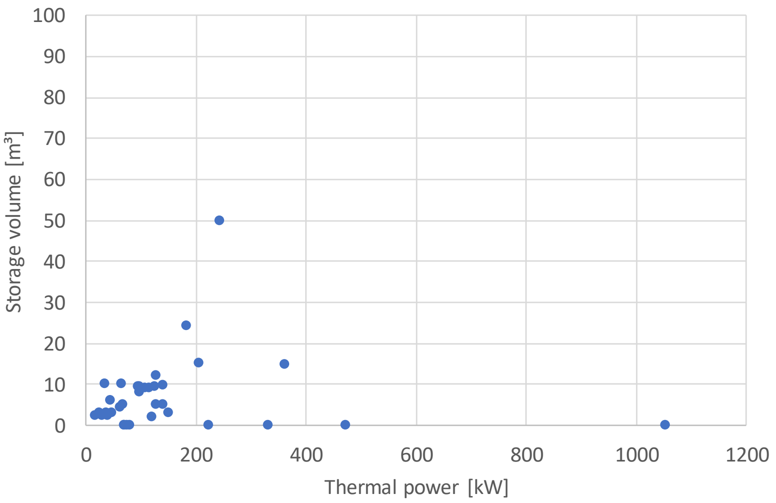
4. Cost assessment and sensitivity analysis

Market review

Storage volume for CSH projects (non-exhaustive)

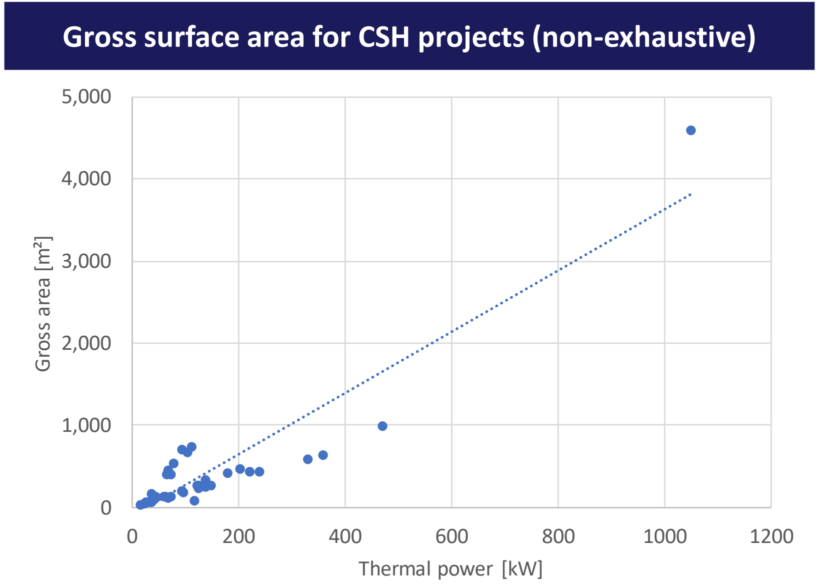


- The majority of CSH projects have storage capacities below 50 m^3 (primarily parabolic trough collectors).
- The average storage volume is 0.07 m^3 per kW (excluding outliers).

Source: AEE INTEC, 2013-2019: *Solar Thermal Plants Database*.

4. Cost assessment and sensitivity analysis

Market review



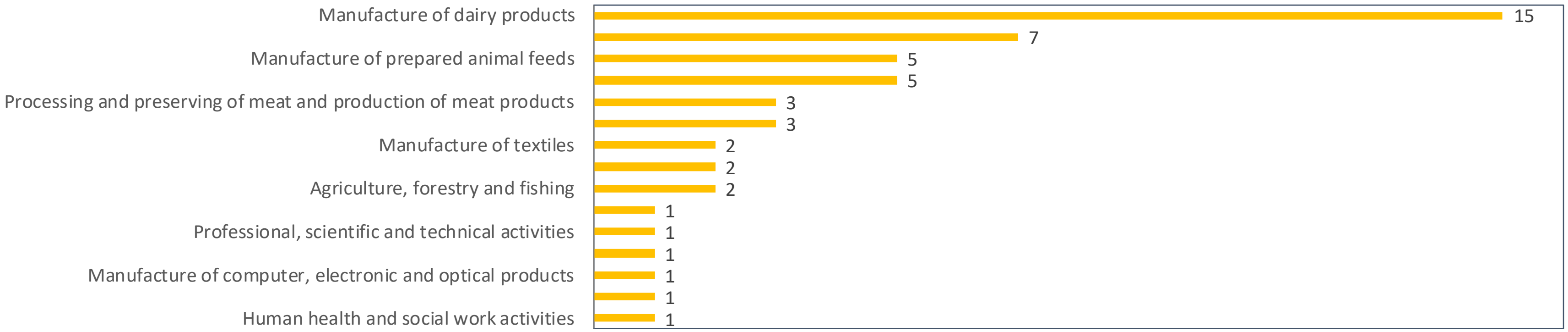
- The average surface area for CSH projects is 3m² per kW (primarily parabolic trough collectors).

Source: AEE INTEC, 2013-2019: *Solar Thermal Plants Database*.

4. Cost assessment and sensitivity analysis

Market review

Number of CSH projects by industrial sector (non-exhaustive)



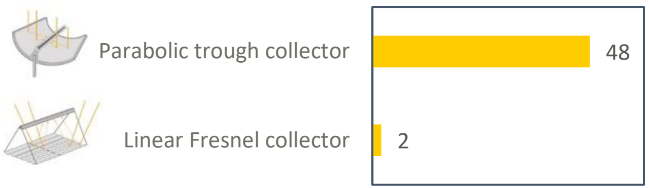
- The dairy, and food and beverage industries are the main sectors in which concentrated solar heat has been deployed.

Source: AEE INTEC, 2013-2019: *Solar Thermal Plants Database*.

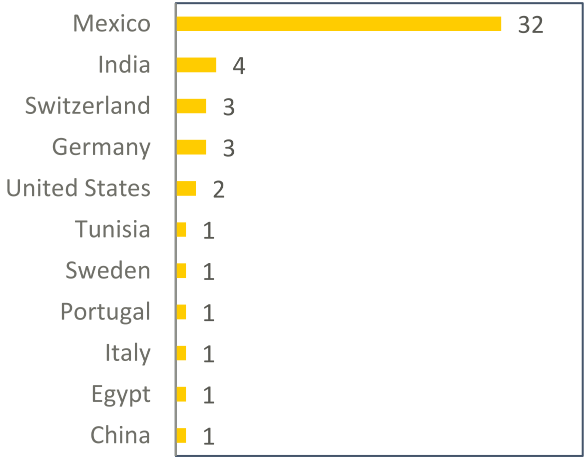
4. Cost assessment and sensitivity analysis

Market review

Current number of CSH projects by collector type (non-exhaustive)



Distribution of CSH projects by country (non-exhaustive)



- Based on the non-exhaustive database of CSH projects, many of these are located in Mexico, with a smaller number of projects in Asia, Europe and Northern Africa.
- The majority of CSH projects use parabolic trough collectors.

Source: AEE INTEC, 2013-2019: *Solar Thermal Plants Database*.

5. Concentrated solar heat SWOT analysis

Strengths

- **Low operating costs** which are not influenced by fossil fuel prices.
- CSH systems are **easy to operate, with low maintenance needs**.
- **Limited regulatory constraints**.
- **Reduces CO_2 and air pollution emissions**.

Opportunities

- Developments in **concentrated solar power (CSP)** collectors and thermal storage can support innovation in CSH. This could lead to increased efficiency and lower costs.
- **New financing models** could reduce the risks and upfront costs to small and medium industrial investors (e.g. heat supply contracts / ESCO models).
- Increasing implementation of **supportive policies** such as carbon pricing and the phase out of fossil fuel subsidies can support the CSH business case.

Weaknesses

- **High upfront capital expenditure (CAPEX)** and long payback periods in a context of low fossil fuel prices charged to the industrial sector.
- **Projects are seldom realized unless they can show short pay-back periods** (<3 years).
- **Low public awareness** of the technology, particularly in the industrial sector, and limited track record, with solar heat accounting for 0.001% of industrial heat consumption.
- **Limited land availability** near industrial facilities hinders implementation of CSH projects.
- **Geographical and climate dependence:** concentrating technologies are limited to areas with good DNI.
- **Thermal storage** for industrial facilities operating 24/7 is needed, but this is not yet proven for all applications, and adds costs.

Threats

- The majority of industrial heat demand (75%) takes place in **large complex industrial sites**. Integration of CSH into such facilities is a challenge as there may be reluctance to interrupt operations at industrial sites where processes are already optimized. This can be overcome by integrating CSH during the construction of new industrial plants.

6. Success factors

Heat demand

Suitable for industrial processes with medium temperature heat demand (150°C-400°C).

DNI

Located in areas of good DNI including Middle East, Africa, India, SW USA, Mexico, Peru, Chile, Western China, Australia, Southern Europe and Turkey.

Land availability

Sufficient land nearby industrial facility is needed. The collector surface area is on average 3m^2 per kW.

Policies

Policies such as carbon pricing, and removal of fossil fuel subsidies improve the competitiveness of CSH compared to conventional fossil fuel alternatives.

Financing models

To overcome high initial investment costs, especially for SMEs, innovative financing models such as ESCO solutions are needed.

7. Concentrated solar heat: Case studies (1/4)

Cement plant

Ciments du Maroc SA (Aït Baha, Morocco)	
Context	• Aït Baha cement plant is located in a remote area, near Agadir with low availability of water and high solar irradiance • The daily production capacity of this energy-intensive process is 5000 tons
Project description & objectives	• On-site pilot CSP plant (1GWh) • Low maintenance • Maximizing the use of local materials • Start date: October 2014
Main technical data	• Parabolic trough collectors • Total active surface: 6000 m^2 • Thermal peak power: 3800 kW • Temperature level: >600°C • Storage capacity: 12 hours • Storage technology: underground reservoir filled up with heat resistant gravel • Annual production: 1000 MWh/year • Total investment: EUR €3 million or EUR €790/kW

Source: Italcementi Group, 2015: *Solar Power and new concrete applications: a pilot plant in Morocco*.

7. Concentrated solar heat: Case studies (2/4)

Farm

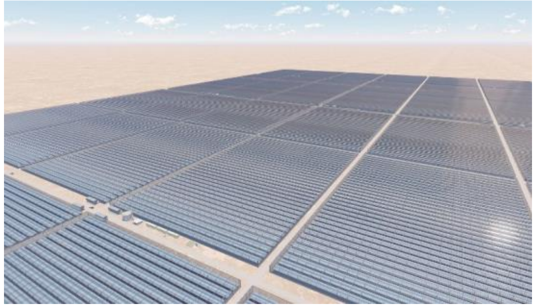
Sundrop Farms (Port Augusta, Australia)	
Context	• Sundrop Farms grows high-value crops in greenhouses located in the South Australian desert using seawater and sunlight as main resources. • Aims to produce over 17,000 tons of fresh vegetables annually
Project description & objectives	• On-site integrated concentrated solar plant provides heating, desalinated water and electricity • Start date: October 2016
Main technical data	• Power tower: 23,000 heliostats (51,505 m^2) reflect sun rays onto the top of a 127m high solar tower • Thermal peak power: 36.6 MW_{th} • Heat production: 20,000 MWh/year • Fresh water production: 250,000 m^3/year • Electricity production: 1,700 MWh/year
Benefits	• Avoided CO_2 emissions: 16,000 tCO_2/year

Source: Aalborg CSP: 36.6mwth integrated energy system based on CSP, Australia.

7. Concentrated solar heat: Case studies (3/4)

Oil field

Petroleum Development Oman (Amal, Oman)	
Context	• Petroleum Development Oman is the largest oil producer in Oman and a joint venture between the government, Shell, Total and Partex. • Natural gas was used to generate the steam used at the Amal oilfield for recovery of heavy and viscous oil.
Project description & objectives	• Instead of using natural gas, Miraah generates the steam required for thermal enhanced oil recovery with an enclosed trough (greenhouse structure protecting the mirrors from wind and sand). This enables the use of lightweight and inexpensive components inside the greenhouse. Automated washing also reduces costs and preserves scarce water resources. • Start date: 2017 (for the first 4 blocks) but construction ongoing
Main technical data	• Total capacity (for the 4 completed blocks): 100 MW_{th} • Total capacity when completed (36 blocks): 1 GW_{th} • Current steam production: 660 tons/day • Steam production when completed: 6000 tons/day
Benefit	• Avoided natural gas consumption: 5.6 trillion Btus/year. • Avoided CO_2 emissions: 300,000 tCO_2/year • Avoid natural gas consumption can be exported or directed toward higher-value applications (power generation / industrial development).

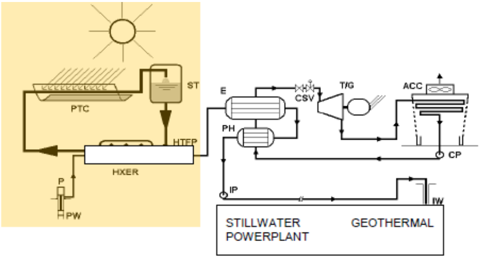


Source: GlassPoint: Miraah; Utilities Middle East, 2016: Oman's Miraah Solar Project Costs Down By 46%.

7. Concentrated solar heat: Case studies (4/4)

Geothermal plant

ENEL Green Power (Stillwater, USA)	
Context	• Stillwater Triple Hybrid Power Plant is located in Nevada, USA • Hybridization of geothermal plant arose from collaboration between ENEL and MIT on augmenting the enthalpy of geothermal reservoirs using solar energy
Project description & objectives	• CSH plant acts as a boiler, which boosts the brine temperature coming from the production wells, just before entering the power plant. The higher temperature increases electricity generation. • Construction started August 2013 • Completion date: August 2014
Main technical data	• Parabolic trough collectors • Temperature: around 199°C • The heat collected by the CSP plant produces an increase of around 6°C in the brine • Rated power: 17 MW_{th}/1.9 MW_e • Load factor: 1446 hours • Capex of USD \$14.5 million or USD \$850/kW_{th} • Maintenance requirements have been limited
Benefits	• CSH injected into the geothermal power plant is estimated to result in a 2.8 GWh/year production increase



Source: Personal communication with Enel.

8. Summary

Emissions and energy	• The industry sector accounts for about 24% of global CO_2 emissions. • Industrial heat demand represents 22% of worldwide energy demand, of which 90% is met by fossil fuels.
Solution	• Concentrated solar heat (CSH) technologies are a low-carbon solution to meeting medium temperature industrial heating requirements. • The technology uses collectors that concentrate sunlight onto an absorber that can reach temperatures between 150°C and 400°C. A heat exchanger transfers this heat for use in industrial processes.
Avoided GHG emissions and co-benefits	• CSH technologies have a positive impact on the industrial user's carbon footprint as the energy source substituted is often a fossil fuel. The direct GHG emissions avoided are dependent on the fossil energy source substituted. • The co-benefits of CSH include reductions in local air pollution, independence from volatile fuel prices and lower operational costs as maintenance needs are low.
Readiness status	• CSH technologies are relatively novel compared to non-concentrating solar heating systems. While not yet mature, solar concentrating technologies will develop in the coming years.
Barriers	• The majority of industrial heat demand (75%) occurs at large, complex industrial sites. Integration of CSH in such facilities is a challenge as industrial sites may be reluctant to temporarily interrupt operations where they have already optimized the processes. • Alternating day/night profile of solar heat requires the integration of thermal storage for industrial facilities operating 24 hours a day, which are not yet proven for all applications and temperatures and increase costs.
Success factors	• Sufficient land near industrial facilities and reliable high solar radiation (clear skies and strong sunlight). • Electricity prices that capture externalities, such as the impacts of carbon pricing or removal of fossil fuel subsidies, to improve the competitiveness of CSH compared to fossil fuel alternatives and reduce its payback time.

9. Key sources and references on concentrated solar heat

- Aalborg CSP: 36.6mwth integrated energy system based on CSP, Australia
- ADEME, 2018: Intégration des énergies renouvelables et de récupération dans l'industrie
- AEE - Institute for Sustainable Technologies, 2018: Solar Heat Worldwide
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