

# A Comparison of Solar Power Systems (CSP): Solar Tower (ST) Systems versus Parabolic Trough (PT) Systems

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## To cite this article:

Huseyin Murat Cekirge, Ammar Elhassan. A Comparison of Solar Power Systems (CSP): Solar Tower (ST) Systems versus Parabolic Trough (PT) Systems. *American Journal of Energy Engineering*. Vol. 3, No. 3, 2015, pp. 29-36. doi: 10.11648/j.ajee.20150303.11

**Abstract:** Comparison of Comparison of Solar Power System (CSP) power plants will be introduced and discussed; Solar Tower (ST) plants and Parabolic Trough (PT) plants are subjects of this comparison. The comparison will be made possibly analytical or quantitatively instead of qualitatively. Examples will be presented and explained in detail. The main issues such efficiency, area of the plant, environmental issues, molten salt storage, the cost of the plants, dust and humidity, maintenance and operation cost and total investment are discussed.

**Keywords:** Solar Tower Power, Parabolic Troughs, Comparison of CSP Power Plants, Environmental Impact of Solar Power, Environmental Impact of Parabolic Troughs, Raspberry Pi, Arduino, Arm Architecture

## 1. Introduction

Several Concentrated Solar Plants (CSP) are at the design, research and development phases, these are mainly, Parabolic Trough (PT), Solar Tower and Linear Fresnel systems. Design limitations combined with economic reasons mean

that the building of Linear Fresnel Power systems was adjourned globally; therefore PT and Solar Tower systems will be compared in this study. Qualitative comparisons of these systems are presented in Table 1.

*Table 1. Qualitative comparison of Solar Tower and PT systems.*

Technology type	Description	Pros	Cons
SOLAR TOWER	Fixed centralized receiver tower surrounded by field of surrounding heliostats	Higher efficiency Minimal piping and fitting Fixed receiver unit Flat mirrors	Few commercial applications ; mostly due to high sophistication of tracking and heliostat allocating software; and heliostat designs which are not spread worldwide in great extent
	Dual-axis control tracking	WI-FI control and single power cable	
	Receiver contains water or molten salt	Proof of concept at first generation sites	
	Storage potential is applicable	Ideal for hybrid plants	
	Field or long rows of parabolic mirrors	Field set-up flexibility Proven development and operational track record	
PARABOLIC TROUGH	Mirrors concentrate sunlight onto movable receiver system	Employs single-axis trackers "Off-Use-shelf" systems available	Relatively low efficiency thermal to electric conversion Utilizes more expensive curved mirrors
	Receiver contains oil or water		Durability of piping and ball joints Environmental issues of oil-based platforms

The reason of minimal commercial utilization of Solar Tower is the sophisticated tracking and control software and WIFI system cannot be offered by many commercial companies. PT's have implementation history in the renewable energy industry. PT's generate energy through heating of the transfer fluid. ST system is based on a number of heliostats and tower boiler, more efficient than the PT systems with the added bonus of not having toxic heat transfer fluid, and efficient use of storage using molten salt.

## 2. Comparison of Solar Tower (ST) and Parabolic Troughs (PT)

### 2.1. Energy Calculations, ST and PT

Considering an Integrated Power Plant, IPP, and Solar Tower can contribute all energy that is needed by the steam turbine, Figure 1, if enough land is provided for hosting the power plant structures.

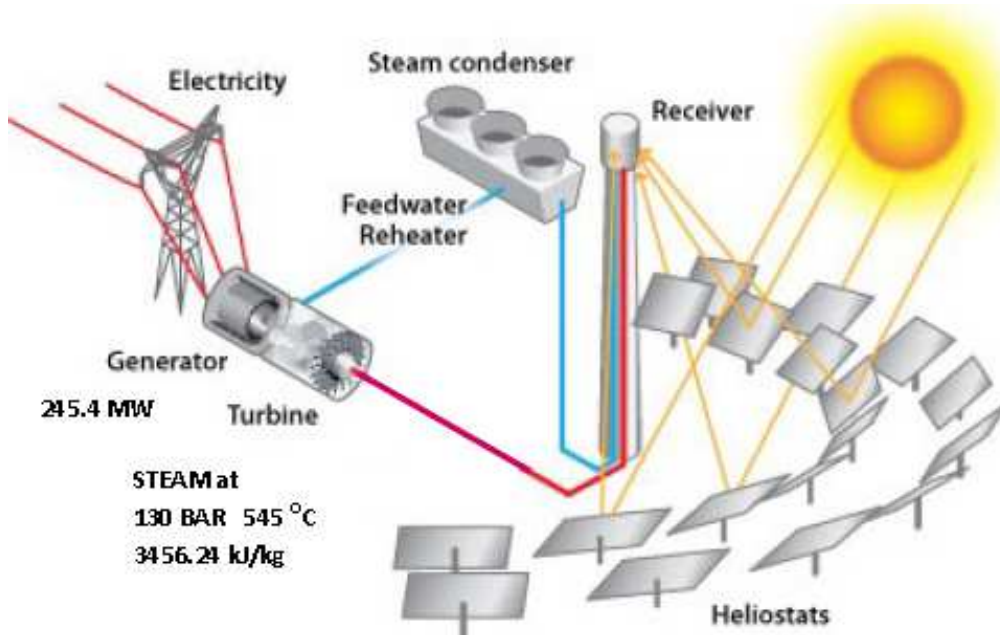


Figure 1. Steam goes to turbine directly from the Solar Tower, [1].

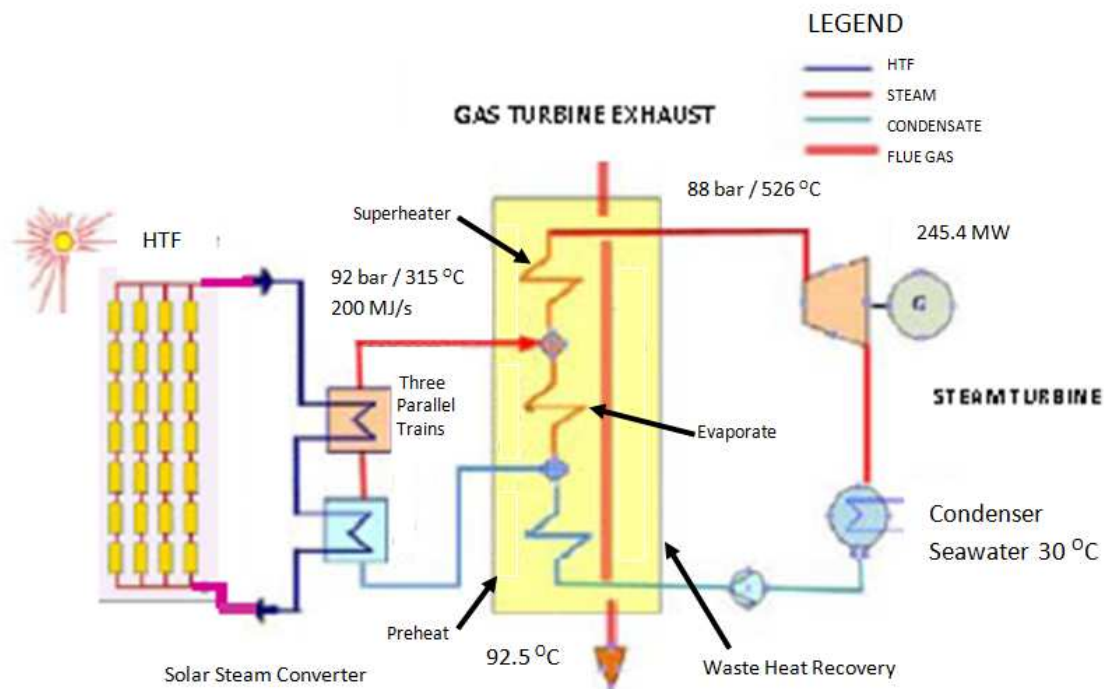


Figure 2. PT with Waste Heat Recovery Boiler, WHRB [1].

In the case of the PT system as in Figure 2, the contribution of solar power is 40 MW and the thermodynamic calculations of enthalpy, entering to and exiting from Waste Heat Recovery Boiler WHRB, were made through [2]. The steam from the PT cannot be used without the utilization of a Waste Heat Recovery Boiler WHRB. As such, gross efficiency is reduced by approximately twenty percent because the heat transferring fluid, HTF, cannot

exceed 400 °C.

PT systems with thermal fluid are not as efficient as CSP Solar Tower systems (ST) that inject steam directly into the turbine; ST systems are approximately 30-40 percent more efficient. In Parabolic Trough type PT plant, the heat transfer is based on thermal oil which can be heated to no more than to 400°C; and degrades and loses efficiency at higher temperatures.

**Table 2.** Thermodynamic calculations of Solar Tower; [2].

IPP_Solar_PT				
Enthalpy_kJ/kg_(exit_pt)_at_bar_	92	°C	315	2791.11
Enthalpy_kJ/kg_(entrance_ST_turbine)_at_bar_	88	°C	526	3453.50
PT_power_MJ/s	200			
Steam_turbine_output_MWe	245.4			
Total_energy_PT_MWe	40.0			

In the case study of a PT system, solar field is operated with a maximum temperature of 393 °C; it delivers heat to the power block where the working fluid is water/steam using a couple of heat exchangers (HX's). At the exit of HX

on the power block, the steam temperature measures 315 °C and 92 bar pressure. The saturation temperature of dry steam at 92 bars is 305 °C, i.e., steam is slightly superheated. In order to utilize steam in the

**Table 3.** Summary of results.

Type	Group	Entry power MW	Steam	Useable MWe
SOLAR ENERGY_PT	IPP	200	92 BAR 315 °C	40
SOLAR ENERGY_ST	IPP	200	130 BAR 545 °C	66

Turbine more efficiently, the temperature needs to be higher; therefore, the exhaust gas from the turbine, at 550 °C, is utilized. The inlet steam of the steam turbine has a temperature of 526 °C at 88 bars. If we consider enthalpies of the steam both at superheated conditions,

$$h(315^{\circ}\text{C}, 92 \text{ bar}) = 2796.65 \text{ kJ/kg},$$

$$h(526^{\circ}\text{C}, 88 \text{ bar}) = 3453.81 \text{ kJ/kg}.$$

In other words, a difference of 657.16 kJ energy per kg of steam is produced by the exhaust gas in the waste heat recovery boiler. This kind of upgrade of solar heat is necessary in PT type installations in order to utilize the steam produced at 315 °C in more efficient high temperature steam turbines. On the other hand, the exhaust gas of gas turbine with a temperature of 550 °C; is sufficient to produce steam in the waste heat recovery boiler (WHRB) with the desired quality to be delivered to the steam turbine. This will be utilized power production without the need of solar generated steam. In addition to lower energy conversion efficiency, limited hybridization capability, long rows of pipes in the field necessary to transport heat transfer oil, and durability of movable heavy structures are taken into account for PT systems.

In the alternative, solar tower (ST) system, CSP plant is already available to produce steam directly deliverable to the high efficiency steam turbine with steam inlet conditions of 88 bars and 526 °C temperature. Therefore, in this scenario,

gas turbine exhaust gas in the Waste Heat Recovery Boiler (WHRB) will produce the same quality steam with the ST CSP plant. This will improve the system performance by about 657 kJ per kg of steam circulating in the intermediate loop. As this is indicated in the block associated with PT plant, 200 MJ/s power requires about 71.5 kg steam circulation per second, i.e.,

$$657 \text{ kJ/kg} \times 71.5 \text{ kg/s} = 46975.5 \text{ kJ/s} = 46.98 \text{ MW}$$

of thermal power is lost due to the inclusion of low quality steam produced by PT system, Table 3.

For implementation purposes, different schemes may be developed for better coupling of WHRB and Solar Tower with steam turbines. In these terms, various scenarios might be developed for comparisons.

## 2.2. Comparison of Land Use ST Versus PT

Land use refers to the land area directly occupied by a power plant structure, ST and PT, and is expressed in units of m<sup>2</sup>/(MWh/y), that is square meter over megawatt hour per year. The visual impact indicating the area over which a power plant disturbs the landscape is measured in units of m<sup>2</sup>/(MWh/y)). Both ST and PT systems are normally setup in remote areas with negligible visual impact. There is always misunderstanding that ST power plants require larger land areas, a typical land use of a ST is presented in Figure 3.

ST system has an algorithm to locate the heliostats in the

field in an optimum way. Besides these algorithms are being tested and perfected in the field for efficient use of heliostat area, [3].

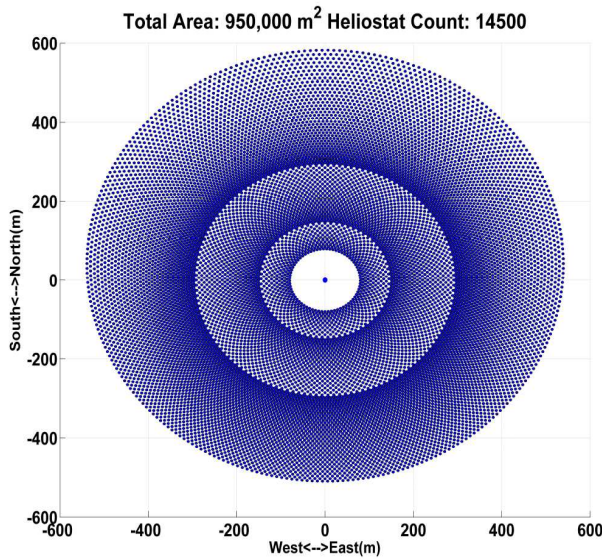
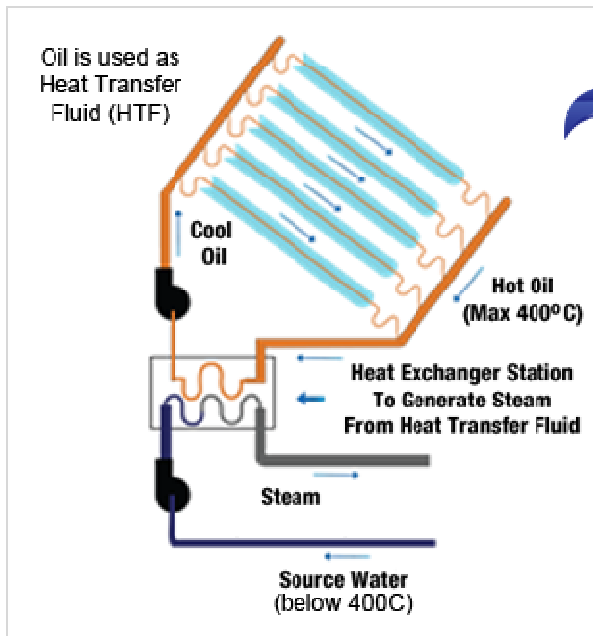


Figure 3. A Solar Tower, ST, "Heliostat" area. [4].

ST system can produce more power than PT system installed equivalent area. ST power system has higher efficiency since the control software has dominant factor to provide maximum solar energy input, [3], into solar power plant.

### Conventional Parabolic Trough



### HITTITE Parabolic Trough

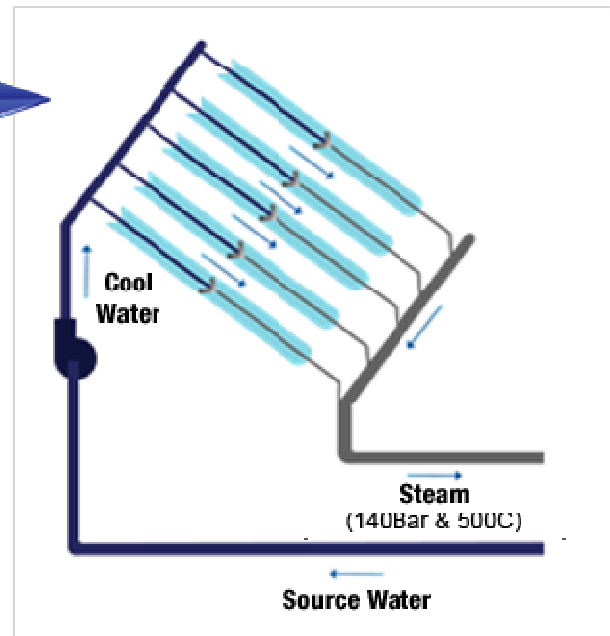


Figure 4. Direct steam generation (DSG), the Hittite PT's, [6].

Molten Salt for ST is less hazardous to the environment since again, HTF is not a factor in the heat exchange process. Water will be used for both systems for cleaning and there must be a source of water close to the plant. In the case of

### 2.3. Environmental Impact of ST Versus PT

The potential environmental pollution risks relating to leaks or emissions of HTF (heat transfer fluids) impact soil, ground and surface water and air quality thus affecting human life. In the case of synthetic oil, as HTF, is used and compared to other possible HTFs, it is friendlier to the environment. PT systems consist of a widespread distribution of the receivers, i.e. tubes or fittings in the solar fields, thus increasing the risk of HTF leakages with the obvious environmental risks associated with it. This aspect is more problematic if the land/site area is not exclusive utilized by to the TES (thermal energy storage) subsystem and the process equipment. In this case, a higher pollution risk threatens the area if leakages of HTF occur in the storage system. There is also an unavoidable HTF odor in installations from leakages since the system has many pipes, fittings and ball joints. The synthetic oil, which it is highly toxic, can pollute the soil and could pass very rapidly to the water systems; MSDN of two HTFs can be found in [4] and [5]. This suggests that oil should be avoided in case of existing vulnerable aquifers. In ST based systems, this kind of pollution is not a factor.

For a solution of this problem in PT systems, steam should be obtained directly [6], which is not common practice, figure 4 illustrates. In these PT's, heat transfer fluid is replaced by water, Hittite Parabolic Troughs, Direct Steam Generation (DSG). The heat storage and efficiency solutions of this system are in development.

desalination, the water problem can be solved without any difficulty. In desert regions, dust is a high impact factor and hence, the CSP requires regular cleaning of the panel surfaces; this can be done by wipers and water spraying. The

daily consumption of water for washing mirrors of ST is quite minimal. Humidity does not play an important role on the efficiency of ST power systems respect to PTs, since STs have flat surfaces.

Other environmental issues such as impact on wildlife have to be analyzed. For example, desert tortoises became a major factor and they were relocated during construction of the Ivanpah plant [7], risk to birds is very minimal and no more than the risk from windows and domestic cats [8]. Many bird mortalities apparently were caused by flight through the hot solar flux, burning feathers and beaks, and others are caused by hitting the heliostats, or anomalies in bird navigation habits.

#### 2.4. Maintenance of ST Versus PT

PT systems consist of a number of pipes, fittings and connections, in other words the system is quite fragile. As an example: Daggett, 103 MW, PT Solar Power Station, located at Daggett, California, USA, the maintenance cost including parts, and excluding Thermal Exchange System, TES and Power Block as at May 2009 is : \$1,289,786.00. This number is quite high, even if loss of production during repairs is notwithstanding [9].

PT systems are made from a disparate set of materials including metal, glass and plastic which are highly susceptible to thermal load thus rendering these systems very fragile. The major problem for all CSP plants is the frequent breakage of expensive parabolic glass mirror panels which are manufactured using highly specialized fabrication processes. These issues must be eliminated, in order to reduce operation and maintenance (O&M) costs. Also, heat receivers must be redesigned to decrease (O&M) costs of the whole system by abandoning traditional “metal to glass attachments”.

Maintenance costs are estimated at around fifteen percent in the favor of ST systems over PT systems, Figure 5 illustrates. It can be seen that breakdown risks are higher in the case of PT systems thus causing loss of income from total production, [10].

#### 2.5. Investment of ST Versus PT

Tables 4 and 5 show investments costs and returns from ST and PT systems. It can be seen that the initial investment for ST is 16 percent less than PT for a typical 100 MW plant. If the storage facilities are considered, the PT system is 42 percent more costly, [11], for the same size plant.



Figure 4. Operations and maintenance costs for PT and ST, [10].

**Table 4.** Current and projected plant cost for 100 MWe power tower with 6 hours storage at Longreach, Queensland, (unit costs based on power tower road map, [12]).

All costs in AUD 2010	Current Cost	Future Cost (2010)	Generic plant sizing	Current Capital Cost	Future Capital Cost (2020)
Site Improvements (\$/m <sup>2</sup> )	27	27	1,010,046 m	\$27,422,752	\$27,422,752
Solar Field (\$/m <sup>2</sup> )	217	130	1,010,046 m <sup>2</sup>	\$219,382,013	\$131,629,208
Receiver & Tower (\$/kWh <sub>th</sub> )	217	185	507353 kWh <sub>th</sub>	\$110,197,072	\$93,667,511
Storage (\$/kWh <sub>th</sub> )	33	22	1,691,180 kWh <sub>th</sub>	\$55,098,644	\$36,732,430
Power Block (\$/kW <sub>e</sub> gross)	1086	869	115,000 kW <sub>e</sub>	\$124,890,000	\$99,912,000
BOP (\$/kW <sub>e</sub> gross)	380	272	115,000 kW <sub>e</sub>	\$43,711,500	\$31,222,500
Indirect Cost			35%	\$203,245,693	\$147,205,240
Indicative Cost (\$/kW <sub>e</sub> net)				\$7,836	\$5,675
O&M (\$/kW-yr)	71	54	100.05 MW <sub>net</sub>	\$7,062,530	\$5,432,715
Solar Multiple			1.8		
Storage Hours			6		
Capacity Factor (%)			40.9		
LCOE (\$/MWh) (20 yr life, WACC 7%)				\$226	\$164

**Table 5.** Current and projected plant cost for 100 MW parabolic trough plant at Longreach, Queensland, current and future unit costs based on, [13], and parabolic trough road map respectively, [14].

All costs in AUD 2010	Current Cost	Future Cost(2017)	Reference plant sizing	Current Capital Cost	Future Capital Cost (2017)
Site Improvements (\$/m <sup>2</sup> )	27	27	918,026 m	\$24,786,702	\$24,786,702
Site Improvements (\$/m <sup>2</sup> )	320	217	918,026 m <sup>2</sup>	\$293,768,320	\$199,211,642
Solar Field (\$/m <sup>2</sup> )	98	46	918,026 m <sup>2</sup>	\$89,966,548	\$42,229,196
Storage (\$/kWh <sub>th</sub> )	87	29	1,877,110 kWh <sub>th</sub>	\$163,308,570	\$54,436,190
Power Block, BOP (\$/kW <sub>e</sub> gross)	1021	884	111,000 kW <sub>e</sub>	\$113,331,000	\$98,124,000
Indirect Cost	18.50%	16%		\$126,754,811	\$70,334,032
Indicative Cost (\$/kW <sub>e</sub> net)				\$8,119	\$4,891
O&M (\$/kW-yr)	80	51	100 MW <sub>net</sub>	\$7,980,000	\$5,130,000
Solar Multiple			2		
Storage Hours			6		
Capacity Factor (%)			43.20%		
LCOE (\$/MWh) (20 yr. life, WACC 7%)				\$223	\$135

### 3. Solar Tracking Sub-System

To maintain maximum efficiency of the system, it is imperative to keep the solar panels pointing towards the sun for as long as possible. There are several methods for achieving this task, varied by cost and complexity. It is proposed that the use of the new breed of ARM-Architecture [16, 17] microcomputers such Arduino [15] and Raspberry Pi [18] coupled with one of three methods of calculating sun

location and ray direction. In both cases below, we propose that solar panels be mounted on motors/actuators that are controlled via relays and microcomputers in addition to a power source (photovoltaic panel or power grid) to power the motors.

#### 3.1. GPS Based Calibration

In this method, the microcomputer with its GPS and Compass sensors will be programmed with the necessary



calibration code to position each solar panel at the correct angle for maximum exposure to sunlight. The cost of this approach is probably the least but only after the algorithm to track in relation to the GPS sensors has been written correctly.

### 3.2. Voltage Differential Based Calibration

By using twin solar panels mounted at right angle to each other, it is possible to read the two harvested voltage values from them and the microcomputer controlled motor/actuator is powered to rotate the platform such that the 2 voltage values from the two solar cells are kept with minimum differential thus guaranteeing that they are pointed at the sun in an optimum way. The cost of this method is higher because it uses two mirrors and requires voltage differential sensors.

### 3.3. Image Based Calibration

By utilizing a Raspberry Pi with a webcam, it is possible to track the location of the sun in the sky using an algorithm to take snapshots of the sky or of a bar shadow [19] and contrast them and rotate the platform accordingly [20] and [21]. The cost of this approach is in-line with the method in 3.1, although this technique has the advantage of being well documented and tested.

## 4. Conclusions

Solar thermal power plant technologies are important sources for providing a significant part of the clean and renewable energy needed in the future. Among these technologies, the qualitative comparison was made between ST systems and PT systems. It has been shown that the ST systems are superior to PT systems in various aspects including:

- ST systems are more efficient, at least 30 percent
- Land area per energy output is 20 to 30 percent in favor of ST systems
- No pollutants or environmentally hazardous materials are utilized in ST systems, hence the energy produced to pollution ratio is much higher
- Operating and Maintenance expenses are around 15 to 20 percent less in ST systems
- Without heat storage sub-systems, ST systems require 15 to 20 percent less upfront investment when considering output based calculations of ST and PT plants. With storage sub-system factored in, this figure is around 30 to 40 percent in favor of ST systems.

At the moment; ST systems are not being commercialized in wide extent, since technology of software and hardware of ST systems are in the hands of few commercial establishments. The software is the major factor; specifically solar tracking and heliostat allocating algorithms are needed to run ST system efficiently; however it is being possessed by limited number of organizations. In addition to all these factors, the ST systems can fit many climatic and geographic conditions.

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