Parabolic Trough Collector Cost Update for Industrial Process Heat in The United States

Sertaç Akar[1] and Parthiv Kurup[1]

[1] National Renewable Energy Laboratory, Golden, Colorado (USA)

Abstract

Despite great potential, the worldwide adoption of concentrating solar thermal (CST) collectors for solar industrial process heat (SIPH) is modest. Industrial process heat (IPH) demands for heat and steam are typically below 300°C, where CST collectors can provide the needed heat. Parabolic trough collectors (PTCs) are the most deployed CST technology for SIPH applications. This paper is focused on the United States, and a summary of known operating parabolic trough plants is shown. A previous analysis of a modern PTC in 2016 found that for SIPH applications, the installed solar field cost could be \$200/m^2 (2016\$). Recent advances in PTC design and manufacturing have led to reduced cost per square meter of aperture area, and for a field of 510 solar collector assemblies (SCAs), the installed cost was \$120/m^2 (2020\$). On one hand, the results from this study showed that the solar field cost for large solar fields (510 SCAs or ~804,000 m^2) would increase to \$184/m^2 (2023\$) due to post pandemic inflation and increase in metal prices. On the other hand, medium SIPH sized fields (90 SCAs or ~142,000 m^2) cost analysis indicated an installed cost could be \$197/m^2 (2023\$). When small SIPH fields (12 SCAs or ~19,000 m^2) are considered, this jumps to \$297/m^2 (2023\$). These are cost estimates for the Installed Cost of the solar fields using the United States 2023\$ steel prices. When Chinese steel is used for comparison, the installed cost could be between \$162 - \$210/m^2 for the range of SIPH sizes.

Keywords: Concentrating Solar Thermal, Solar Industrial Process Heat, Parabolic Trough Collector

1. Introduction

Thermal energy and steam are ubiquitous needs in industrial process heating (IPH) applications. From the extraction of raw materials to food processing, heat is a vital part of the processing and manufacturing sectors. Globally, 53% of the final energy consumed by industrial processes is for heat such as heating fluids, processing materials, and reactions (IEA, 2023). In the United States, nearly 70% of the IPH demands are less than 300°C (McMillan et al., 2023). Linear concentrating solar thermal (CST) systems (i.e., parabolic troughs) can take heat transfer fluids (HTFs) and provide renewable heat for IPH up to 300°C (McMillan et al., 2021).

Global interest in using solar thermal for providing heat has been steadily increasing. Particularly in countries like China, Denmark, and Germany, solar thermal is used for solar water heating (SWH), solar district heating (SDH), and solar IPH (SIPH) applications. At present, flat plate collectors (FPCs) like glazed and unglazed collectors are widely used for SWH, and as of 2022 there were 542 gigawatts thermal (GWth) of global installed capacity. For SDH and SIPH, the installed capacities were 1.795 GWth and 0.856 GWth respectively (Weiss and Spörk-Dür, 2023). 75% of the total SIPH capacity (0.645 GWth), was installed at 494 sites. In 2022, 30 megawatts thermal (MWth) of SIPH capacity was installed (Weiss and Spörk-Dür, 2023).

When the number of SIPH systems is considered, parabolic trough collectors (PTCs) are used less than FPCs. There were 219 operating FPC sites for SIPH compared to 65 for PTCs, but the MWth installed is greater for PTCs i.e., 366 MWth compared to 219 MWth (Weiss and Spörk-Dür, 2023). There is significant potential for PTCs for SIPH applications. For example, when the Ma'aden Solar 1 site in Saudi Arabia is considered, it could be the largest SIPH plant at 1.5 GWth (Weiss and Spörk-Dür, 2023). This SIPH site would provide steam for alumina processing, which could reduce gas consumption by 12 million (MM) British Thermal Units (BTUs) per year and save 600,000 tonnes of CO_2 emissions per year (Glasspoint, 2023a). Whilst such large CST plants are very important to be deployed to reduce costs, such large projects may not be completed. For example the Miraah plant in Oman for solar thermal enhanced oil recovery was originally expected to be 1,021 MWth (Kraemer, 2017), and of that 330 MWth was finally constructed and is in operation (Glasspoint, 2023b).

Another technology suitable for SIPH are the Linear Fresnel Collectors (LFCs). Major advantages of LFCs are having potentially lower cost optical components due to its nearly flat shaped mirrors instead of curved mirrors, and potentially lower operating and maintenance (O&M) since the receiver tubes are fixed and so flexible

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hoses or ball joints as used in PTCs are not needed (Pulido-Iparraguirre et al., 2019). The German company Industrial Solar (lately named PSE AG) used LFCs in several projects, such as the solar/gas cooling plant at the Engineering School of Seville, Spain (Haeberle et al., 2006). The most recent example of LFC SIPH application is the 4 MWth solar field that meets 10% of the steam demand at a Valencian brewery developed by HEINEKEN and CSIN (Solatom Indertec Company). This 4-MWth solar field has an aperature area of 6,000 m^2 and 182 Fresnel modules (HEINEKEN Spain, 2024).

This paper looks at the use of CST for SIPH applications at less than 300°C and is primarily focused on the United States and highlights PTC examples in the United States, a PTC installed cost update (in 2023$), and an analysis of the impact of global steel prices to PTC installed costs. It is worth noting, concentrating solar power (CSP) PTCs can be used for electricity generation and heat generation. Depending on the land availability and the heat generation needed, large aperture PTCs can be used for IPH applications.

2. PTC examples in the United States

There are only four SIPH plants installed using PTCs in the United States with a total capacity of 5.56 MWth (Tab. 1), of that 2.48 MWth is operational. To note, SkyFuel`s and Industrial Solar Technology (IST) Corp`s sites are not operating. The IST site was designed to deliver pressurized water from the solar field at 450 Fahrenheit (Walker et al., 2007), or 232°C. There have been reported issues of the solar field integration at the IST site, which included lower utilization of the energy used from the solar field than planned (86% instead of 100%), and higher soiling rates than expected (Kurup and Turchi, 2015). At the water desalination pilot site, the commercial readiness and performance of the electricity generation PTC and multiple effect distillation (MED) system was shown, though the electricity generation PTCs were underutilized in terms of the exit temperature of the solar field (180°C needed for the MED system compared to the PTC design of 390°C), and the cost of the treated water was expensive (Kurup and Turchi, 2015). There have been other CST demonstrations utilized for SIPH in the United States, such as LFCs (Kincaid et al., 2019; Kraemer, 2020).

Tab. 1. A summary of PTCs used for SIPH in the United States (*currently not operational)

Location	Developer	Application	Capacity (MW_{th})	HTF	Source
CA	Sunvapor	Almond Pasteurization	2.30	Water	(Epp, 2022)
CA	SkyFuel	Water Desalination*	0.48	Water & Glycol	(WaterFX, 2015)
AZ	Rackam	Sludge Drying	0.18	Synthetic Oil	(SPM, 2021)
CA	IST Corp	Food processing*	2.6	Pressurized water	(Walker et al., 2007)

2.1. Food Processing Application in California, USA

Sunvapor constructed and put into operation in 2022 a 2.3-MWth solar steam facility for almond pasteurization in Madera, California (CA) (Epp, 2022). The PTCs during the construction phase are shown in Figure 1 (Sunvapor, 2022), and water is heated through the PTCs to then produce steam with a solar steam boiler (Epp, 2022). The project is expected to achieve a 50% reduction in natural gas consumption per year, and a 100% reduction during clear sky conditions (Sunvapor, 2022).

Figure 1. 2.3 MWth solar steam facility for almond pasteurization in Madera, CA [(Epp, 2022), Image credit: Sunvapor]

2.2. Waste Management Application in Arizona, USA

Environmental laws require municipalities to treat wastewater sludge. There are many methods for decontaminating and disposing of sludge. Solar heat can be used to dry the sludge and prepare it for incineration or use as fertilizer. Solar heat can also be used in arid regions to distill and recover water-settling ponds. This gives two products with high added value, drinking water and fertilizer for crops. Rackam developed an innovative solar drying solution for sludge drying in City of Surprise, Arizona (AZ) (Figure 2) (SPM, 2021). Rackam proposed a dryer that combines solar heat generated by its PTCs and a ventilated greenhouse to evaporate water contained in the sludge with a very high efficiency (Rackam, 2024). The dryer is equipped with a feed system, a discharge system and multiple automated flipping tools that insure uniformity of the dried product. At full operation the goal is to reduce biosolid weight from 27 wet tonnes per day to 8 dry tonnes per day, approximately a 70% reduction by weight (SPM, 2021).

Figure 2. 175 kWth solar waste management system in City of Surprise, AZ (Image Credit: Rackam)

3. Global Market Analysis of Steel

CST solar fields that provide heat or generate electricity utilize significant quantities of commodity materials. These include steel, glass, cement, and aluminum, which can generally be locally sourced, leading to the development of an integrated supply chain (Chung et al., 2016; Turchi et al., 2015). Large PTC fields can have between 33% - 44% purchased components (Kurup et al., 2022). The majority of these specialized or purchased components such as mirrors and receivers, are typically bought from countries such as Germany or China.

For this paper, the PTC design utilized in the cost analysis (Section 4) is primarily steel based. For CST plants, typically low-carbon structural steel is used and then galvanized to allow for outdoor corrosion protection (Kurup et al., 2022; Turchi et al., 2015). A large PTC solar field can be approximately 31% carbon steel, iron, zinc and stainless steel by mass in metric tonnes (Turchi et al., 2015), as such changes in the raw steel price will fundamentally drive the solar field Installed Cost ($\$/m^2$). This section looks at the global and U.S. markets for steel to highlight the significant impacts in steel price over the last 5 years.

3.1. Global steel analysis

Steel as a key commodity material, produced in many forms from hot rolled coil (HRC), structural plates, tubes and pipe, and rebar (SteelBenchmaker, 2024). Steel grades also vary by end-use from stainless steel to low-carbon steel. HRC is a typical and principal steel product, and an indicator of raw material, and overall market steel prices (Ryerson, 2020). Figure 3 shows the HRC price per metric tonne by country, and the fluctuations from 2014 to 2024. This highlights that United States domestically manufactured steel (in $/tonne), has over the last decade been significantly higher than Chinese and European steel. During the pandemic in 2020, significant price hikes for HRC in $/tonne increased from ~$500/tonne to nearly $2,000/tonne (4 times increase). HRC $/tonne prices saw sharp declines in 2023 (Figure 3). At present the United States HRC is approximately $777/tonne (SteelBenchmaker, 2024; Trading Economics, 2024).

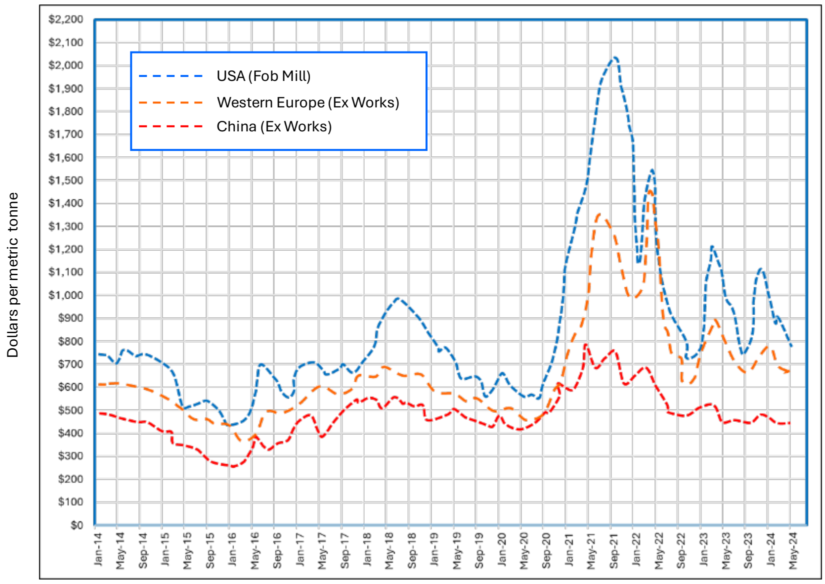

Figure 3. HRC steel prices (in dollar per tonne) for USA, Western Europe and China (SteelBenchmaker, 2024)

3.2. United States steel analysis

With the focus of this paper on the United States, the U.S. steel market is also shown. Steel for CST IPH applications is likely to be sourced in the United States to offer domestic benefits such as reduced transportation. Figure 4 shows the Total Price of Steel Index spanning from 1980 to 2024. Relative to 2020's 184.5, by 2023 the index was considerably higher at 319.9 i.e., a 73% increase (Ibis World, 2024). The Total Price of Steel is determined from the "producer price index for steel mill products, averaging the growth in price for various types of steel, including bars, sheets, strips, plates and wires, of the hot-rolled and cold-rolled varieties. The index has a base year of 1982" (Ibis World, 2024).

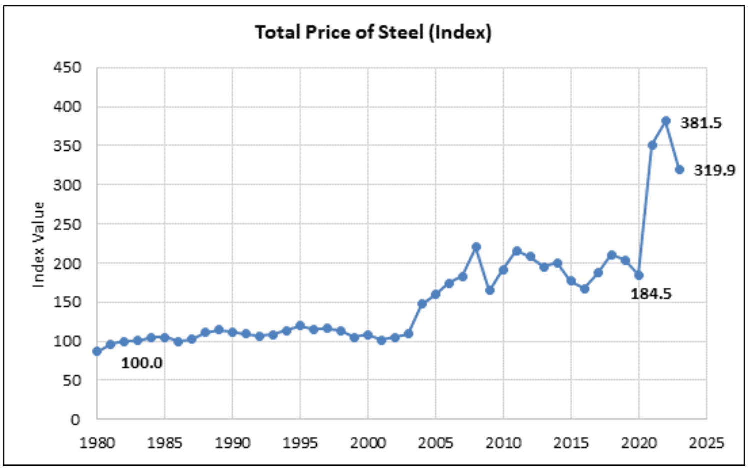

Figure 4. Total Steel Price Index from 1980 to 2024 (Ibis World, 2024)

4. Parabolic Trough Collector Cost Update Methodology

Previously an installed cost analysis and a manufacturing methodology for a state-of-the-art and a near-commercial parabolic trough solar collector assemblies (SCAs) was developed (Kurup et al., 2022; Turchi et al., 2016). An SCA is built of a string of PTC modules controlled by a single drive and represents the smallest unit of a functional parabolic trough solar field. In this context, an updated bill of materials (BOM) was provided by Solar Dynamics for the SunBeam™ 8-m aperture width mid-term collector (Figure 5). The cost of specialty components such as receiver tubes, drive systems, and glass mirror panels were based on quotes from representative suppliers. Design for Manufacturing and Assembly (DFMA®) software is used to calculate detailed manufacturing and assembly cost of the system at different manufacturing volumes. The DFMA® tool has detailed databases and allows the knowledgeable user to calculate a primary manufacturing cost for each component and then assemble it within the overall product/assembly.

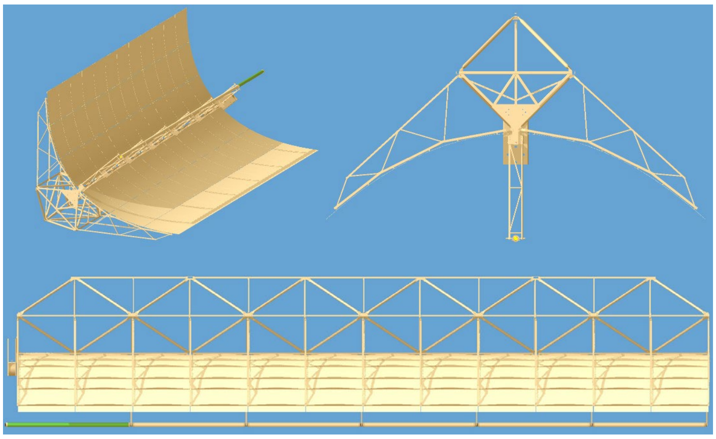

Figure 5. Schematics of SunBeam™ PTC Mid-term Design (Image Credit: Solar Dynamics)

The estimated solar field installed cost per square meter as a function of the number of SCAs built is given as (Eq. 1):

$$Solar\ Field\ Cost\ \left(\frac{\$}{m^2}\right) = \frac{Manufacturing\ Cost\ (\$) + Assembly\ Cost\ (\$)}{(Number\ of\ SCAs) * (Area\ per\ SCA)\ (m^2)} \quad \text{(eq. 1)}$$

The installed cost analysis for the PTC System includes manufacturing costs, in-house assembly costs, outsourced parts and field assembly cost. In the scope of this cost update first the BOM and manufacturing cost model is updated based on a medium size and a small system size which consists of 90 SCAs and 12 SCAs of SunBeam™ collectors respectively. The manufacturing costs are calculated by using the DFMA® software`s updated material and process libraries in version 2023a. The cost estimates purchased parts such as mirrors, drive hydraulics, control systems, fasteners, interconnected and electrical cabling are escalated to 2023 dollars by using the U.S. Consumer Price Index for urban customers (CPI-U) (BLS, 2024) and new price quates from vendors.

An earlier analysis found that the PTC solar field installed cost could be \$200/m^2 (2016\$) sized for SIPH applications with 10 SCAs (5MWth), and ~\$180/m^2 for approximately 500 SCAs (Turchi et al., 2016). In another analysis from 2020, the solar field cost was calculated as \$120/m^2 (2020\$) for a large CST system with 510 SCAs and ~1,570 m^2 aperture area per SCA (Kurup et al., 2022). The estimates for 2023 showed that the solar field cost for 510 SCAs could be 53% more than the 2020 results.

5. Results

5.1. Installed Cost Analysis

The installed cost for large size PTC system assuming a production volume of 510 SCAs, which is representative of a solar field of approximately ~800,000 m^2 is calculated as \$184/m^2 (Figure 6a). This solar field, which occupies approximately 1,000,000 m^2 of land area, is suitable for 225 MWth in Daggett, CA with a solar multiple (SM) of 2.3 and six hours of thermal energy storage (TES) (NREL, 2024). The manufacturing cost also includes an estimated \$934,000 investment cost to purchase tooling specific to the manufacturing of the steel components for the space frame, support arms, and receiver supports. When the total manufacturing tooling investment (i.e. stamping dies) is amortized over 510 SCAs, it adds \$1.2/m^2 to the manufactured cost.

The installed cost for medium size PTC system assuming a production volume of 90 SCAs, which is representative of a solar field of approximately ~142,000 m^2 is calculated as \$197/m^2 (Figure 6b). This solar field, which occupies approximately 177,000 m^2 of land area, is suitable for a 40 MWth solar field with the same SM and TES configuration. Total tooling investment is the same as large size PTC system and it adds \$6.2/m^2 to the manufactured cost when the total manufacturing tooling investment for stamping dies is amortized over 90 SCAs.

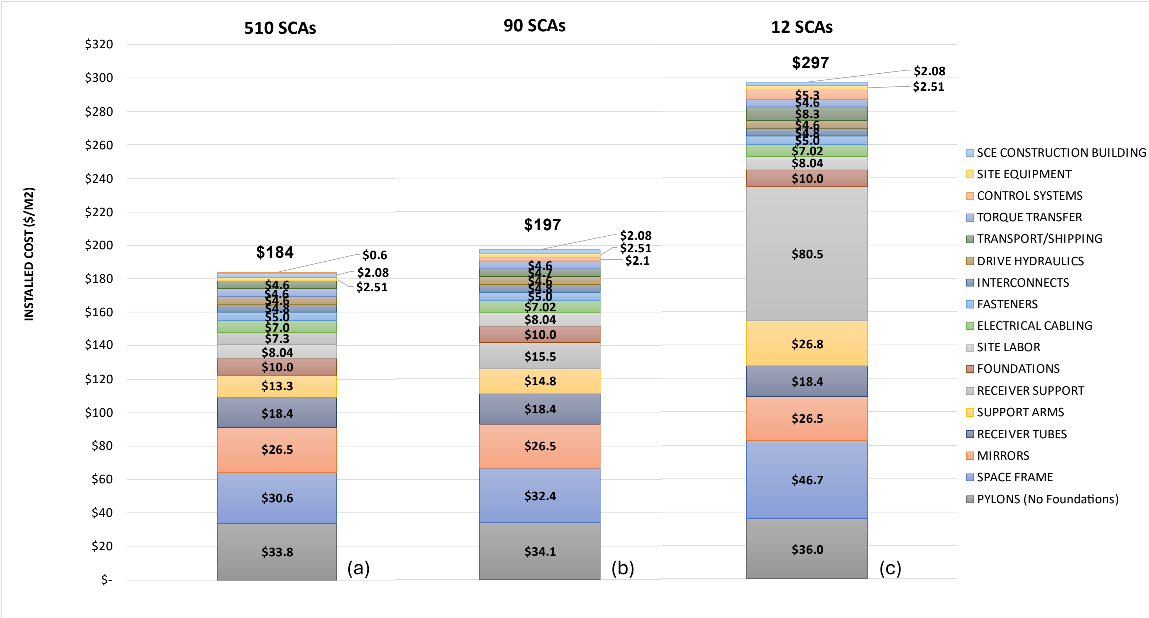

Figure 6. Installed cost breakdown by component for a) 510 SCAs SunBeam™ PTC, b) 90 SCAs SunBeam™ PTC, c) 12 SCAs SunBeam™ PTC

The installed cost for small size PTC system assuming a production volume of 12 SCAs, which is representative of a solar field of approximately ~19,000 m^2 is calculated as \$297/m^2 (2023\$). This solar field, which occupies approximately 24,000 m^2 of land area, is suitable for a 5 MWth with the same SM and TES configuration. The manufacturing cost analysis of the small size PTC system includes machining, in-house assembly and purchased items, assuming a production volume of 12 SCAs. When the total manufacturing tooling investment is amortized over 12 SCAs, it adds \$49.4/m^2 to the manufactured cost. In an earlier study, the installed cost of a similar sized 10 SCA, 5 MWth solar field in 2016\$ was \$200/m^2 (Turchi et al., 2016). When comparing this aluminum space frame design to the 12 SCA steel frame design, the installed solar field cost has increased to \$297/m^2 (2023\$). The current analysis indicates the steel components have the highest cost share followed by the mirror panels and the receiver. While unit cost steel components correspond to ~52-54% of the installed cost of 510 SCAs and 90 SCAs, this share can jump to 67% for the 12 SCAs (Figure 7).

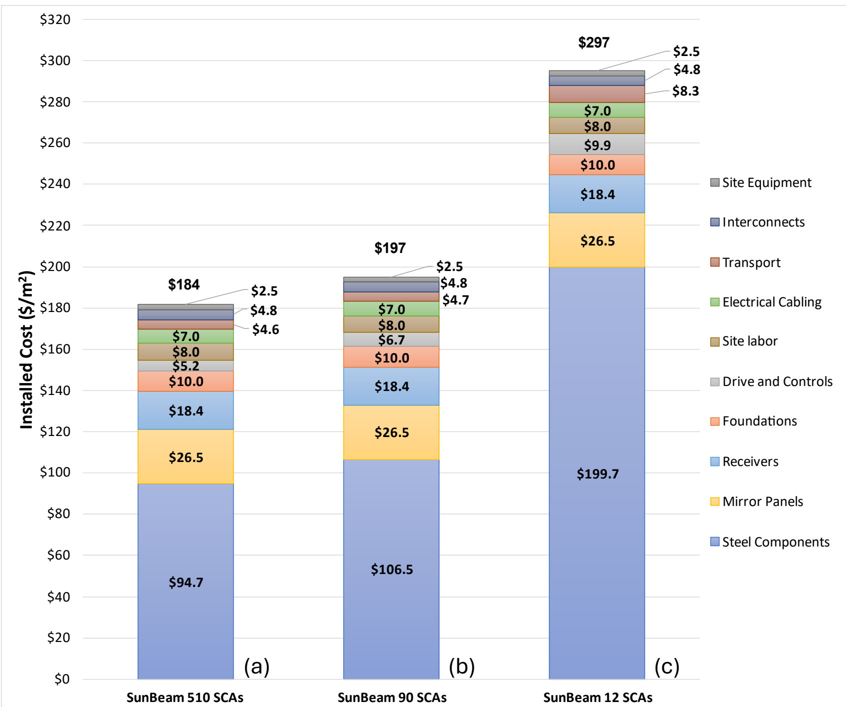

Figure 7. Cost share of steel components in a) 510 SCAs SunBeam™ PTC, b) 90 SCAs SunBeam™ PTC, c) 12 SCAs SunBeam™ PTC

5.2. Impact of Global Steel Prices

The DFMA® software has the option to select the material library which allows the user to select the sources of the material for concurrent costing. It can be either North American Origin, or Chinese origin materials. Using the 2023 databases, the analysis indicated that the large size PTC system can be 10% cheaper, the medium size PTC system can be 12% cheaper, and the small size PTC system can be 28% cheaper when Chinese origin steel is used as raw material for manufacturing processes (Figure 8). It is important to note that, while the material cost is taken from Chinese origin with estimated shipping cost, remaining cost items such as, the operation times, labor rates and energy costs are still representing the North American rates.

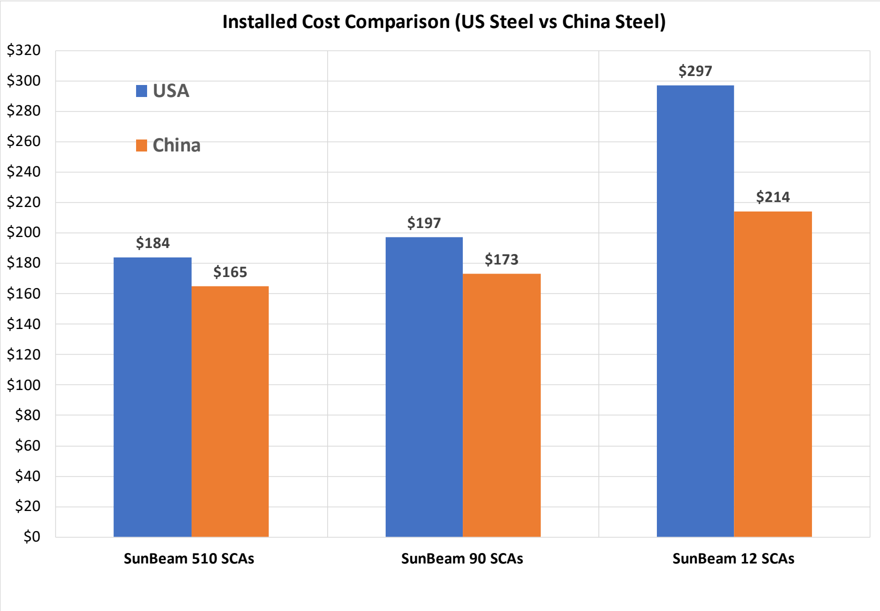

Figure 8. Comparison of the installed cost for large, medium and small field aperture area PTC systems with respect to the USA and Chinese origin steel as raw material.

The steel price analysis undertaken in this work has only looked at the relative price difference such as $297/m^2 for the solar field installed cost compared to $214/m^2 for the same 12 SCA design, which has utilized United States or Chinese steel respectively. Estimated average cost of shipping for steel from China to the United States is $175/tonne (Basenton, 2024) which corresponds to a $3/m^2 cost adder to the total installed cost. Specific tariffs have not been considered, which aim to increase the competitiveness of U.S. Steel. For example, the current "tariff rate on certain steel and aluminum products under Section 301" is 0% – 7.5% (White House, 2024), has not been added. This same tariff has been announced to increase to 25% in 2024 (White House, 2024), with the impacts which would be seen in 2025 and later. The impact of tariffs has been excluded, as that requires specific project and supplier information, which was outside of this scope. The steel prices in the United States and China have been highlighted to help give perspective on the choice for companies looking to develop SIPH projects in the United States are likely to face higher CAPEX costs due to local steel being relatively higher than sourced from Europe or China.

5.3. Levelized Cost of Heat (LCOH) for SIPH applications in the United States

For an industrial site that is considering the use of SIPH, an important evaluation is whether to install a renewable heat solution such as a PTC solar field and the heat conversion hardware (i.e., HTF to steam generator) to integrate it into the site. This analysis assumes that a brownfield industrial site (i.e., with existing infrastructure), has two options: the site could install a PTC solar field adjacent to the site; or replace an existing natural gas burner. Industrial gas burners are commonly used to produce steam, and can range in cost such as $102 - $250/kWth (Akar et al., 2021; Karki et al., 2019). We have utilized a 5 MWth system capacity for the commercial natural gas boiler, operating at 83% efficiency (DOE FEMP, 2022a). Industrial steam boilers can operate for approximately 1,500 – 6,000 full load hours equivalent depending on the industry and use case (DOE FEMP, 2022b; Loes, 2019; Rissman, 2022). It is expected that the boiler would ramp up and down and have partial loads during operations. We have used 3,000 full load hours equivalent, based on 5,500 hours of annual operation (Cleaver Brooks, 2020), and a $234/kWth natural gas installation cost (Rissman, 2022).

Natural gas fuel costs are important to highlight in this analysis, as any industrial site would compare their natural gas costs due to operating their plant to the SIPH application. The SIPH application would save them costs, reduce volatility, and increase the security of their energy supply. 2023 U.S. and state level Industrial Price of gas ($ per thousand feet and converted to $ per MMBTU) have been used (EIA, 2024).

The LCOH is an important and convenient metric that shows the estimated lifetime cost of the PTC solar field and installation for SIPH and comparing it to the LCOH of replacing an existing natural gas steam boiler. The LCOH for SIPH is similar to the Levelized Cost of Electricity (LCOE), where renewable electricity generation technologies can be compared. The LCOH method used is from SAM (NREL, 2024; Short et al., 1995), and (Eq. 2) shows the LCOH calculation. The total installed project cost is the TIPC, the fixed charge rate is FCR, Annual O&M is the Annual Operating and Maintenance (O&M), and the annual thermal generation (which for simplicity is the same every year) is based on direct normal irradiance (DNI) at different places in the United States. The TIPC includes the solar field installed cost and additional hardware such as the HTF system to generate steam and heat exchanger, site preparation costs (i.e., $25/m^2), contingency on Direct Capital (CAPEX) Costs at 7% and Indirect CAPEX cost at approximately 10%. The SAM Industrial Process Heat Parabolic Trough model has been used to obtain the SIPH estimates relating to the solar field integration.

$$LCOH = \left(\frac{\$}{kWhth}\right) = \frac{(TIPC)*(FCR)+(Annual\ O\&M)}{Annual\ thermal\ generation} \quad \text{(Eq. 2)}$$

Figure 9 shows the LCOH for a range of installed solar field costs (not the total cost per m^2) at three different DNI levels that are representative of the United States, and the LCOH of a replacement 5 MWth natural gas boiler. For example, as can be seen the U.S. average LCOH for the natural gas boiler replacement was $0.025/kWhth and the CA average was approximately $0.059/kWhth. The LCOH for gas is based on 2023 industrial gas prices of $4.42/MMBTU for the United States, and $12.74/MMBTU for CA (EIA, 2024). A United States average industrial gas price of $4.42/MMBTU corresponds to $0.015/kWhth of natural gas price, and similarly $12.74/MMBTU in California corresponds to $0.043/kWhth. As seen in Figure 10, if the installed solar field cost is approximately $200/m^2 in an excellent solar resource area which has an average DNI of 7.5kWh/m^2/day (i.e., Daggett in CA has an average estimated daily DNI of 7.67 kWh/m^2/day (NREL, 2024), the LCOH of the PTC field could be approximately $0.025/kWth. In CA, which has a range of DNIs from 5.5 to over 7.5/kWh/m^2/day, natural gas costs are significantly higher than the U.S. average, and solar fields at $150 – 300/m^2 could yield an LCOH less than the natural gas system.

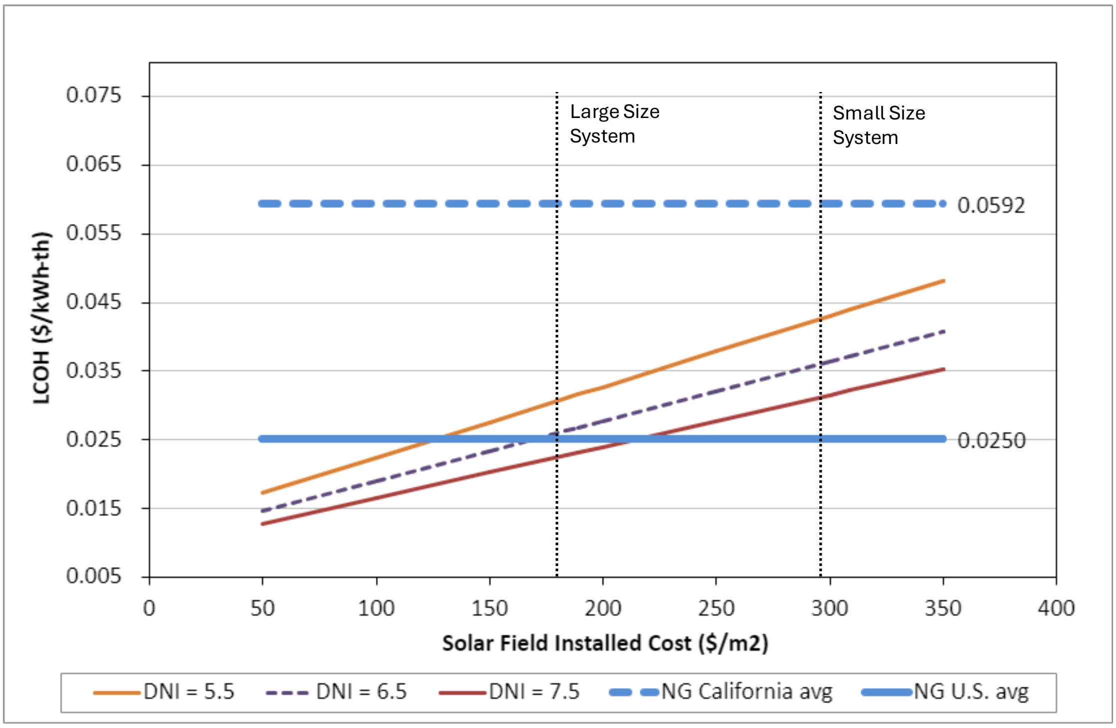

Figure 9. LCOH for a range of installed costs and three different solar resource levels that are representative of the United States.

Figure 10 shows the range of the LCOH for a range of installed solar field costs across the 3 DNI resource levels, and with 3 different gas prices ranging from \$5/MMBTU to \$10/MMBTU. This in 2023 is representative of natural gas price for most states in the United States, as 11 states in the United States had natural gas prices over \$10/MMBTU (a LCOH of \$0.0479/kWth) (EIA, 2024). As expected, as the natural gas price decreases from \$10/MMBTU to \$7.5/MMBTU and then to \$5/MMBTU, it becomes significantly more difficult for PTC SIPH fields to compete directly without subsidies or credits against low natural gas LCOHs. For example, if a site has \$10/MMBTU natural gas pricing, even with a lower DNI of 5.5 kWh/m^2/day and \$350/m^2 for the installed solar field cost, it can produce a competitive LCOH of approximately \$0.0479/kWth. In a gas price environment of \$7.5/MMBTU such as AZ, which also has very good to excellent DNI, installed solar fields costs up to \$300/m^2 could have a LCOH lower than \$0.0377/kWhth.

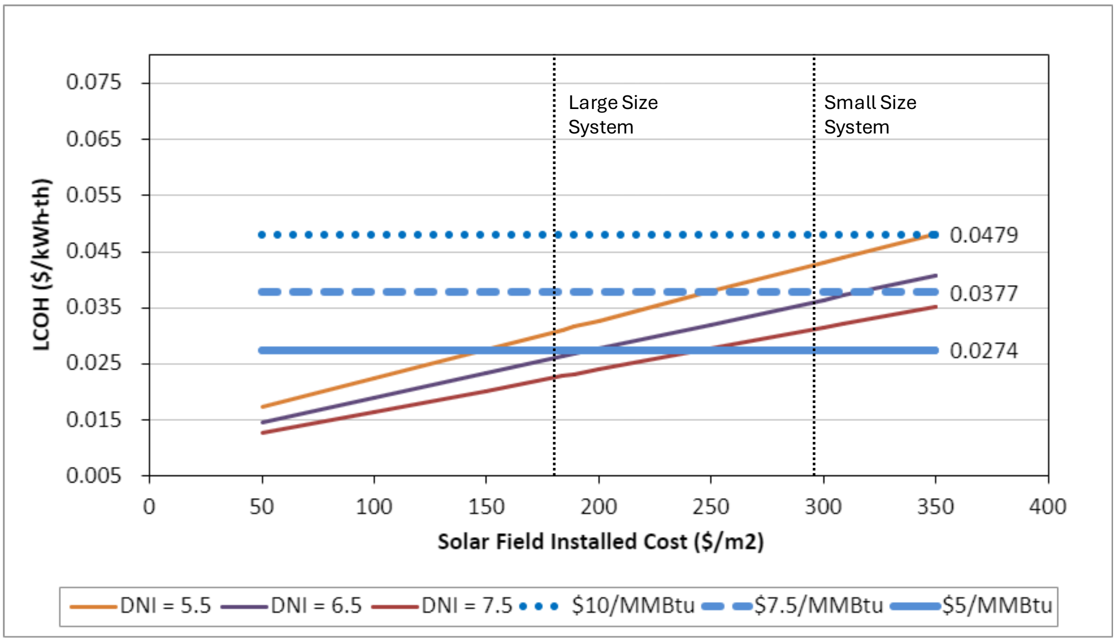

Figure 10. LCOH across gas price ranges (\$7.5/MMBTU in AZ)

6. Discussions

6.1. Volume of Manufacturing & Economies of Scale

The volume of manufacturing is the key for the parts to be economically feasible to manufacture in-house. While the manufacturing processes which do not require additional tooling such as laser cutting do not have a significant impact on the part cost, processes like heavy stamping which require significant tooling cost have a great impact on the unit cost of the part. The economic threshold varies by the type of material and the size of the part to stamp but on average 10,000 parts is the economic limit for a part to be stamped at low manufacturing cost (Figure 11). While the average manufacturing volume for a large size PTC system (510 SCAs) could be ranging between 40,000 and 100,000 parts, it is as low as ~1,000 parts for a small size PTC system (12 SCAs). Thus, the economic threshold for the IPH application should be at least 9-10 projects at size of 12 SCAs per year.

A one SCA prototype is just for test purposes and does not represent a cost feasible IPH application (~0.4 MWth). The solar field installed cost of a one SCA prototype could be as high as \$1,465/m^2 with North American steel and \$750/m^2 with Chinese steel. Similarly, to make the one SCA IPH application economically feasible the manufacturer should have a project volume ranging between 90 and 100 PTC systems per year.

Design changes can have a positive impact on the installed solar field cost of the PTC systems. Considering 50-60% of the total installed solar field cost comes from the material cost, any design change that requires less parts and materials in the structural frame can lower the installed cost significantly. Another important factor that affects the cost of manufacturing is the change in process. As an example, replacement of stamping with roll forming or increased automation in manufacturing and assembly such as robotic arm riveting would reduce the total installed cost of the PTCs.

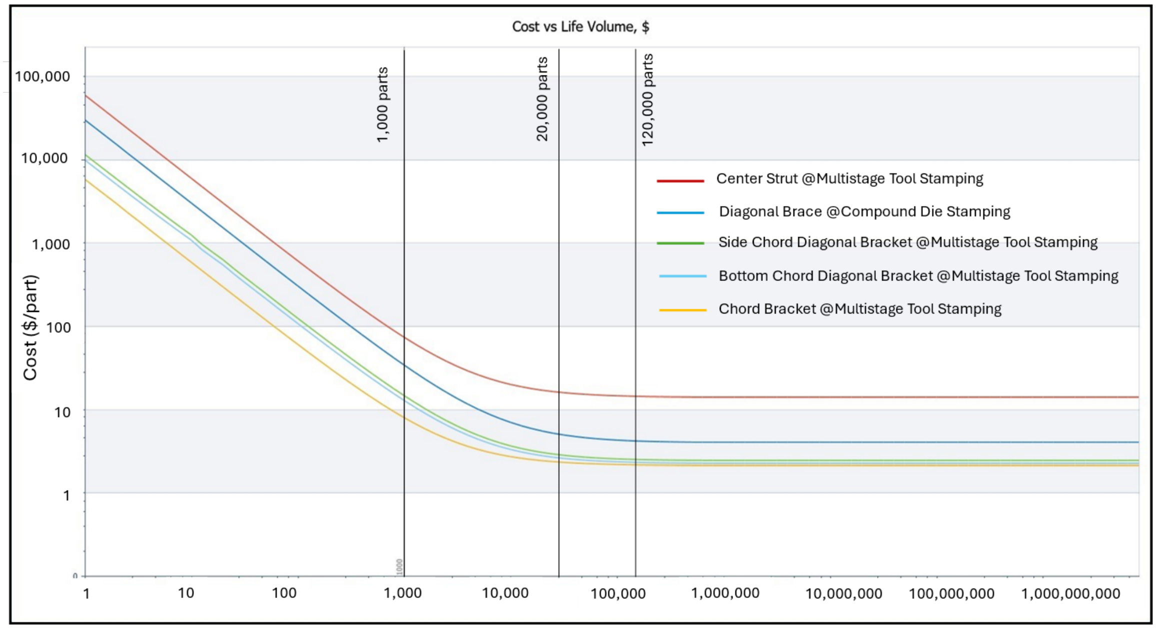

Figure 11. Cost vs volume chart for parts manufactured by stamping processes which require additional tooling

6.2. LCOH Discussions

This study finds that CA represents a favorable environment for SIPH since the natural gas prices are typically significantly higher than the national average, and DNI values are excellent. CA typically also has strong incentive programs for renewable energy technologies. The LCOH for SIPH improves or reduces as the raw steel prices drop, the solar field integration costs decrease e.g., the piping and HTF to steam generator, and contingencies reduce as learnings increase and there are more solar field installations. When natural gas prices stay high, or a tax credit is applied for carbon emissions, the LCOH for SIPH applications becomes more competitive when compared to the heat generated by the existing natural gas systems. This study assumes a 5-MWth system capacity for the SIPH application, and as such would be higher than the LCOH of a medium size PTC system (40 MWth), which can utilize the volume of manufacturing, and economies of scale highlighted earlier.

6.3. Global Examples of Small Aperture area PTCs for IPH

This analysis has highlighted large aperture PTCs, which have the potential to be utilized for SIPH applications (e.g., 5 MWth), if sufficient thermal load can be met by the field and there is land area adjacent to the industrial site. PTCs designed originally for electricity generation and then used for SIPH are operating, such as the 30 MWth PTC solar field integration at the Heineken España site (Epp, 2023). Typically SIPH applications utilize smaller PTCs such as 1-2 m of aperture width, which are suitable for rooftop applications (Figure 12a), or ground mount for size constrained sites (Figure 12b).

Figure 12. a) Absolicon`s rooftop PTC for IPH application in Greece (RTC, 2023); b) Inventive Power's ground mount application in Mexico (Rosell, 2022). Image Credits: Absolicon and Inventive Power

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