Technology Position Paper

Solar Heat for Industrial Processes (SHIP)

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Contents

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This position paper explains the relevance, present status and potential of the development and market of Solar Heat for Industrial Processes (SHIP), leading to actions needed to further and best exploitation. It addresses policy, decision-makers, and influencers and aims to present high-level information as a basis for the uptake and further development of SHIP.

1 Introduction and Relevance

Solar Heat for Industrial Processes (SHIP) has enormous potential in industrial decarbonization, addressing the industrial sector's **total final low and medium temperature heat consumption**, corresponding to 12% of the total final energy demand worldwide. The major share of the energy needed in this sector is used for heating and cooling production processes at temperatures up to 400 °C and is almost exclusively provided with fossil fuels, as shown in Figure 1. SHIP technologies are market-ready to significantly reduce CO_2 emissions in these applications using non-concentrating solar thermal collectors (up to 150 °C) and concentrating collectors (up to 400 °C). Solar applications for even higher temperatures are under development but not the subject of this paper.

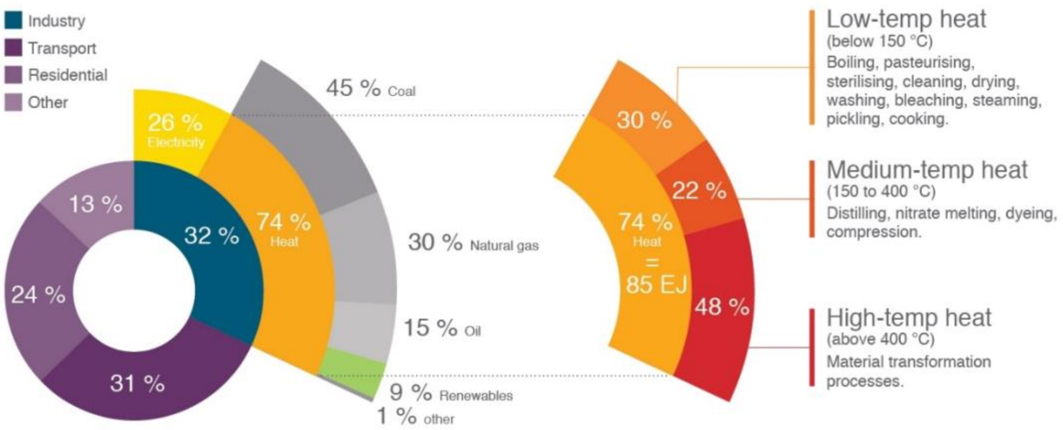

Figure 1. Total final energy demand, share of heat demand, temperature levels, and current energy carriers for industry worldwide. [1]

SHIP is a simple and easy-to-integrate heat supply system and can be combined with any other technology, as proven in hundreds of successful implementations worldwide (see below). With a smart concept design that includes proper storage technology, solar heat can be provided 24/7, also in times with low or no solar radiation.

So far, the focus for decarbonizing heat supply has been on electrification and modern bioenergy, as shown in Figure 3. However, the recent disruption in the energy supply has proven that **diversification** in terms of energy carriers and applied technologies is not only needed but must be mandatory to ensure a reliable energy supply at low and predictable energy prices. Solar heat enables countries, communities, and companies to increase their independence and stabilize energy supply costs for the next decades.

The SHIP industry is based on a **strong, sustainable, and reliable supply chain** and is attractive with its low dependence on rare earth and critical materials. High recycling rates of its core materials, metals, and glass make it highly attractive for circularity. The technology can

[1] Source: https://www.solar-payback.com/wp-content/uploads/photo-gallery/.original/Enourmous_Global_Heat_Demand_in_Industry_EN.jpg?bwg=1587229039

be easily scaled to the end-user's demand with few limitations, as successful implementations have shown worldwide.

It is obvious that the carbon-free provision of heat at low and medium temperatures is of high relevance, and SHIP is a core technology in that field. Many industrial companies require sustainable solutions and thus create a pull market.

Comparative studies[2] of different markets show that typical cost reductions by early market development and economies of scale also apply to SHIP systems. However, the technology is still at the beginning of its learning rate curve.

The total technical potential of SHIP is far above the current installed capacity. Increased implementation will lead to significant project cost reductions and further accelerate cost competitiveness in key markets. In summary, SHIP is a market-ready technology with >1,000 successful implementations worldwide to meet the enormous market potential.

2 Current Status

SHIP technologies are market-ready and available for low and medium temperature ranges up to 400 °C. Around 70 turnkey providers worldwide plan, install, and operate SHIP systems acting on a strong and reliable supply chain. An increasing number of SHIP technology suppliers provide heat delivery contracts. In these models, specialized "Energy Service Companies" (ESCO) offer solar heat solutions and services to industrial clients, including designing, installing, financing, operating, and maintaining energy-efficient technologies and selling the heat at a fixed price for a specified contract period.

The recent years have shown a dynamic market development for SHIP. In 2022, 84 new plants with a total collector area of 39,600 m² (27.8 MW_{th}) were installed worldwide and documented on the online SHIP database[3]. The SHIP database currently documents 494 SHIP systems worldwide with a total collector area of 1,072,000 m². Similarly, a market survey that asked solar companies about their installed collector areas in the SHIP market reported 1,089 installed systems by the end of 2022 with 1,220,000 m² of total collector area (equal to 856 MWth),[4] of which 114 systems were installed in 2022. The two sources show a good correlation in terms of total collector area and thermal capacity but not in the number of systems because the SHIP database is less likely to document smaller systems.

The following figure shows the market development of the documented SHIP systems from 2000 to 2022 in terms of the number of systems installed annually and the total collector area installed annually. Looking at the period between 2013 and 2022, it becomes evident that, with some fluctuation, especially from 2020 to 2022, the annual market is relatively constant, with an average of around 40,000 m² of collector area installed per year (corresponding to 28 MW_{th}). Even though some plants are in the MW_{th} range, a clear trend towards larger plants has not yet been discernible. The actual number of installations is expected to be higher since not all plants, especially smaller ones, are documented.

2 IRENA (2020) Renewable Power Generation Costs in 2020

3 AEE INTEC (2023) SHIP database www.ship-plants.info, derived on 31.03.2023

4 Solarpayback (2023) Annual surveys among the companies listed on the SHIP Supplier World Map https://solarthermalworld.org/news/high-level-of-dynamism-on-the-ship-world-market-in-2022/

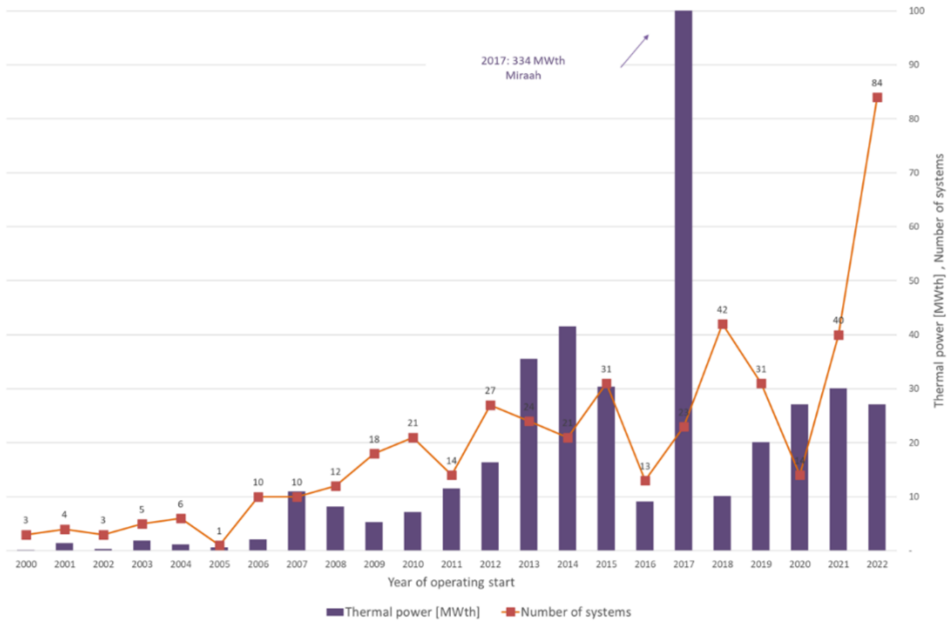

Figure 2. Documented annual installation of SHIP systems from 2000 to 2022 on the www.ship-plants.info database.

To correctly understand the market position of SHIP, the number of SHIP installations has to be evaluated in relation to the overall energy demand: Based on the 2020 worldwide annual total final energy consumption in industry (approx. 33,000 TWh), the share of renewable heating was 0.1% according to the Renewable 2023 Global Status Report[5]. Assuming specific solar useful heat delivery of 550 kWh/m²/yr, SHIP installations currently contribute 0.6 TWh or 0.0020% to the total final energy consumption of industries worldwide. Although only some of this demand is well suited to be replaced by SHIP, the potential is still enormous.

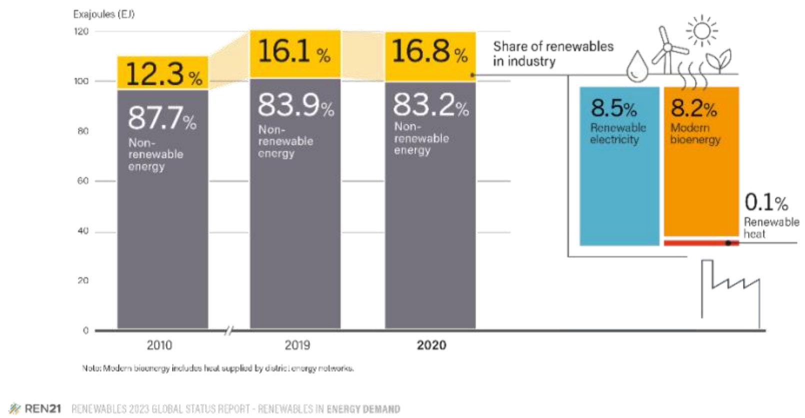

Figure 3. Renewable share of total final energy consumption in Industry. [5]

The small fraction of renewable heat today is explained by the low costs of fossil heat in combination with the missing obligation to use renewable heat in industry. Consequently, SHIP systems are implemented only if there is a (short-term) economic benefit for the companies. Currently, the levelized cost of heat (LCOH) of implemented SHIP plants is typically 30 to 70 €/MWh, mainly depending on the temperature level, load profile, and plant size. Recent studies highlight that European installation costs dropped significantly between 2014 and 2020 due to economies of scale. Further cost reductions due to learning rate effects are expected, driven

[5] REN21 (2023) Renewable 2023 Global Status Report – Renewables in Energy Demand

by strong market growth. Cost reductions are expected for all types of SHIP systems, with the highest impact on technologies that achieve higher temperatures. At the same time, increasing plant size (>500 m²) positively impacts system costs in general and indirectly affects smaller plants below 500 m².

A hurdle for SHIP systems investment decisions is that it is a long-term investment, which may not align with expectations for quick payback periods of less than three years. However, SHIP plants bolster energy security and ensure long-term, predictable, low-price stability for industrial companies.

3 Potential

The market potential

The total process heat demand worldwide was about 46,000 TWh in 2021[6]. Applying the parameter for the potential studies of IEA SHC Task 49 (Irradiation of 1,200 kWh/(m²a), 40% annual efficiency), a conservative potential for the SHIP share of at least 4% or 1,850 TWh is calculated. This is equivalent to a collector area of more than 3,900 million m² (2,730 GW) or investments of 1,900 billion €. Compared to the current market situation of around 30 MW/a installed SHIP capacity per year, SHIP's potential is almost untapped.

Recently, sectors such as food & beverage, machinery, mining, and textiles have grown. However, there is strong potential for all industries with operating processes in the temperature range up to 400 °C or supply systems with a (pre-)heating demand. The analysis of several hundred industrial heat load profiles clearly shows the dependency of industrial heating demand on ambient temperatures for the space heating of production halls. However, almost all sectors have a process heat demand that is more or less constant throughout the year[7]. Heat is also needed in summer, which suits solar heat delivery. Properly sized systems reach solar fractions above 50% and, when combined with other renewable heat sources, bring the systems up to 100% fossil fuel free solutions.

In contrast to fossil-based solutions, renewable energy, and SHIP solutions specifically contain a high regional added value and the creation of green jobs. However, investors and companies still lack awareness of SHIP systems and their opportunities.

Cost reductions

While energy prices are rising significantly and suffer from high volatility and dependency on global developments, an installed SHIP system can deliver 100% CO_2-free energy at fixed costs for at least 20 years. Successful implementations prove that competitive LCOH of 30-70 €/MWh can be achieved under favorable conditions. Public funding systems with investment grants can help to make installations profitable in other cases and can be helpful to trigger broader market penetration. Despite the slow market development in the past, a significant decrease in LCOH has been reached in the last ten years in several countries by the reduction of installed costs (20 to 55% cost reduction).[8] This effect of economies of scale has the potential to start a self-reinforcing development. The resulting learning rate of large solar heating plants can decrease the costs of all solar heating systems if the implemented collector area is large enough. A logical conclusion is that solar heat can be the base

[6] IEA (2022), World Energy Outlook 2022, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

[7] M Jesper, F Pag, K Vajen, U. Jordan, Annual Industrial and Commercial Heat Load Profiles: Modelling Based on k-Means Clustering and Regression Analysis, Energy Conversion and Management: X 10 (3) (2021) 100085, doi:10.1016/j.ecmx.2021.100085.

[8] IRENA (2020) Renewable Power Generation Costs in 2020

technology for the industrial heat transition and help companies be more independent from other heat supply costs.

The role of SHIP as part of decarbonization strategies

There is a demand for CO_2-free solutions to provide industrial process heat. Industry is requesting short-term solutions to decarbonize its mainly fossil-based energy systems worldwide. And climate targets are becoming the core argument for renewable energy technologies, getting a huge push from climbing fossil fuel and electricity costs. Direct electrification and synthetic fuels are considered for high-temperature applications above 400 °C. However, these energy carriers are expected to be too scarce and valuable for low-exergetic applications if better alternatives are available.

Gone are the days of competition between renewable technologies as stand-alone systems. In recent years, the shift towards hybrid systems (SHIP, waste heat, heat pumps, PV, PVT, geothermal, and storages) is clear.

SHIP provides attractive characteristics for hybrid systems: low heat generation costs, integrated thermal storage solutions, and attractive installation area requirements. Due to its low demand for critical raw materials and high recycling rates, SHIP stands out as a key component of an overall heating solution.

Large heat storages that enable adaptation of supply and demand profiles are the core of both stand-alone SHIP and hybrid systems. Storage increases the solar fraction of the total energy supply cost-efficiently by shifting the solar supply to low-radiation times.

SHIP systems are flexible in their design and can be integrated into most industrial heat supply systems. To have the most significant impact, a SHIP system should be integrated on the supply side of a company's heat generation system and meet specific conditions, such as temperature level, load profile, and space availability. Integration concepts addressing diverse processes, industries, and heat supply systems are available[9]. The German standard VDI 3988 "solar process heat" offers, for example, a quick first assessment of the SHIP system design based on a simple but reliable methodology targeting summer heat demand. If more space is available, the solar collector area can be increased to use economies of scale and increase the solar fraction. SHIP benefits from thermal collectors' significantly higher solar-to-heat conversion efficiency at higher temperatures than heat generation with resistance heaters powered by photovoltaic (PV) installations. The required installation area for a PV system is about two to three times larger than for a SHIP installation. For industrial applications, this systematic advantage is significant. For low-temperature applications, the effect is compensated by using PV-heat pump systems.

4 Actions Needed

The many discussions at experts' meetings within SHC Task 64 have identified the following challenges and means to strengthen the market uptake of solar heat for industrial processes.

Challenge	Action needed	Action addressed to
Economic framework	SHIP is a long-term investment often in conflict with typical short planning horizons in industry. Thus, **appropriate national support mechanisms** are needed**:**	Policy makers, politics

[9] B Muster, I Ben Hassine, A Helmke, S Heß, P Krummenacher, B Schmitt, H Schnitzer. Integration Guideline. Deliverable B 2, IEA SHC Task 49, 2015

	- Longstanding, clear targets for emissions reduction, fossil fuel reduction, or renewable heat adoption in Industry - Implementation of significant carbon prices - Strategic investment (CAPEX) subsidy schemes for SHIP to foster learning curve effects. - Public or private guarantee mechanisms to mitigate risks in the viability and afford-ability of ESCO schemes and reduce cost of capital until market is sufficiently established. - Support of detailed feasibility studies in the MW-scale (best practice in Austria)	
Public awareness	**Raise awareness on the role of SHIP** in CO2 free, reliable heat supply at projectable cost, independent on energy markets and with high local content. **Continuous information** on companies, industry associations and politics. **Collaborate** with well-established **industrial engineering companies** to establish SHIP within their standard portfolio. **Include SHIP integration** as one of the default technologies in decarbonization in **studies, publications, and political discussio**n.	SHIP Industry, R&D, industrial engineering companies
Capacity building	**Train** energy managers, engineers, project developers and installers to pave the way for strong market growth, especially in emerging markets. **Cooperate** with **industrial engineering companies.**	SHIP Industry and R&D
Planning tools	**Support commercially available software** for planning hybrid SHIP systems (heat pump, solar thermal, concentrating collectors, steam systems and the integration in industrial processes). Validate tools with operation data and include a requirement to report performance data for tool validation to reduce risks.	SHIP Industry and R&D
Modularity and design standardization	**Standardize plug-and-play solutions** for SHIP and make easy to integrate and combine with other technologies.	SHIP Industry, R&D
Solutions for hybrid heat systems	**Develop detailed design guidelines**. SHC TCP work can be the basis for formalizing official design guidelines.	SHIP Industry, R&D
Quality infrastructure	**Develop simple fault detection systems**. **Scientific monitoring** of subsidized large systems and **know-how-transfer** of lessons-learned.	Solar companies and R&D, politics
Cutting costs	Use learning rate and scaling effects for large projects (Think BIG). Provide continuous **support for applied R&D** to further cost reductions.	Solar companies and R&D, politics incl. funding agencies