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IEA SHIP

Coordination of an IEA SHC / SolarPACES Joint Task on Solar Process Heat

IEA SHC TASK 64 | IEA SolarPACES Task 4 | Solar Process Heat

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Summary

The industrial sector accounts for approximately 30% of the total energy consumption in the OECD countries. The major share of the energy that is needed in industrial companies, services and agriculture is used for heating and cooling of buildings and for production processes at temperatures from ambient up to approx. 400 - 500 °C. This is a temperature range that can be addressed with solar thermal technologies at a high TRL.

To be able to make use of solar heat in industry and to support this market sector for the solar thermal industry, it is necessary to integrate solar thermal systems into the energy supply schemes in a suitable way.

The main objective of the IEA SHC / SolarPACES Joint Task 64 / IV was to identify, verify and promote the role of solar thermal systems in combination with other heat supply technologies such as fossil and renewable-fuelled boilers, combined heat and power plants, or heat pumps.

Task 64 started in January 2020 and formally ended in December 2023 and was divided into five subtasks: Subtask A - Integrated Energy Systems, Subtask B - Modularisation, Subtask C - Simulation and Planning Tools, Subtask D - Standardisation/Certification, Subtask E - Market Introduction Guide. All project results are available on the task website https://task64.iea-shc.org.

Zusammenfassung

Auf den Industriesektor entfallen etwa 30 % des gesamten Energieverbrauchs in den OECD-Ländern. Der grösste Teil der in Industrie-, Dienstleistungs- und Landwirtschaftsbetrieben benötigten Energie wird zum Heizen und Kühlen von Gebäuden und für Produktionsprozesse bei Temperaturen von Raumtemperatur bis zu ca. 400 - 500 °C verwendet. Dies ist ein Temperaturbereich, der mit solarthermischen Technologien in einem hohen TRL adressiert werden kann.

Um Solarwärme in der Industrie nutzen zu können und diesen Marktsektor für die Solarthermie-Industrie zu unterstützen, ist es notwendig, solarthermische Anlagen in geeigneter Weise in die Energieversorgung zu integrieren.

Das Hauptziel des IEA SHC / SolarPACES Joint Task 64 / IV war es, die Rolle von Solarwärmeanlagen in Kombination mit anderen Wärmeversorgungstechnologien wie fossil und erneuerbar befeuerten Kesseln, Kraft-Wärme-Kopplungsanlagen oder Wärmepumpen zu identifizieren, zu verifizieren und zu fördern.

Die Task 64 startete im Januar 2020 und endete formal im Dezember 2023. Sie gliederte sich in fünf Subtasks: Subtask A - Integrierte Energiesysteme, Subtask B - Modularisierung, Subtask C - Simulations- und Planungswerkzeuge, Subtask D - Standardisierung/Zertifizierung, Subtask E - Leitfaden zur Markteinführung. Alle Projektergebnisse sind auf der Task-Website https://task64.iea-shc.org verfügbar.

Résumé

Le secteur industriel représente environ 30 % de la consommation totale d'énergie dans les pays de l'OCDE. La majeure partie de l'énergie nécessaire aux entreprises industrielles, aux services et à l'agriculture est utilisée pour le chauffage et le refroidissement des bâtiments et pour les processus de production à des températures allant de la température ambiante à environ 400 - 500 °C. Il s'agit d'une plage de températures à laquelle les technologies solaires thermiques peuvent répondre à un niveau de TRL élevé.

Pour pouvoir utiliser la chaleur solaire dans l'industrie et soutenir ce secteur de marché pour l'industrie thermale solaire, il est nécessaire d'intégrer les systèmes solaires thermiques dans les schémas d'approvisionnement en énergie d'une manière appropriée.

L'objectif principal de la tâche commune 64 / IV de l'AIE SHC / SolarPACES était d'identifier, de vérifier et de promouvoir le rôle des systèmes de chauffage solaire en combinaison avec d'autres technologies d'approvisionnement en chaleur telles que les chaudières à combustibles fossiles et renouvelables, les installations de cogénération ou les pompes à chaleur.

La Task 64 a débuté en janvier 2020 et s'est officiellement terminée en décembre 2023. Elle était divisée en cinq sous-tâches : Subtask A - Systèmes énergétiques intégrés, Subtask B - Modularisation, Subtask C - Outils de simulation et de planification, Subtask D - Standardisation/certification, Subtask E - Guide de mise sur le marché. Tous les résultats du projet sont disponibles sur le site web de la tâche https://task64.iea-shc.org.

Main findings («Take-Home Messages»)

- Three quarters of the energy demand of industry is heat. 50 % of this heat is used at temperatures from just above ambient temperature to approx. 400 °C, that can be delivered by of the shelf market-available solar thermal technologies.
- For efficient decarbonization, SHIP (Solar Heat for Industrial Processes) technologies can be integrated in hybrid systems with e.g. waste heat, heat pumps, PV, PVT, geothermal.
- Large heat storages that enable adaptation of supply and demand profiles increase the solar fraction of the total energy supply cost-efficiently by shifting the solar supply to low-radiation times.
- The total technical potential of SHIP is far above currently installed capacity. Increased implementation will lead to significant project cost reductions and further accelerate cost competitiveness in key markets.

Contents

List of abbreviations

AIE	Agence internationale de l'énergie
BoP	Balance of Plant
COP	Coefficient of Performance
e.g.	for example
EXCO	Executive Committee
GIS	Geographical Information System
HP	Heat Pump
i.e.	that is
IEA	International Energy Agency
LCOH	Levelized Cost of Heat
N/A	Not applicable
NPL	National Participation Letter
OA	Operating Agent
SFOE	Swiss Federal Office of Energy
SHC	Solar Heating and Cooling
SHIP	Solar Heat for Industrial Processes
SolarPACES	Solar Power and Chemical Energy Systems
ST	Solar Thermal
TCP	Technology Collaboration Programme
TM	Task Manager

1 Introduction

1.1 Context and motivation

Solar Heat for Industrial Processes (SHIP) was already subject of two joint IEA SHC / SolarPACES Tasks: No 33 / IV and No 49 /IV. Both Tasks have achieved substantial progress for solar technology entering the market segment “heat for industry”. But although growing, still the market volume is far below expectations: worldwide we see less than 1’000 SHIP installations.

On the other hand, the potential for solar heating systems that provide heat to industry is still considered to be relevant: in the order of 2 % to 4 % of a central European country’s total industrial heat demand can realistically be provided directly by solar technologies, installed on available (roof, ground and façade) areas. The potential in sun belt countries is even bigger. SHIP can be a considerable contribution to CO_2 reduction.

The goal of Task 64 / IV was to help solar technologies be (and also be recognized as) a reliable part of process heat supply systems. These are hybrid supply systems and will have to be integrated in the upcoming developments of the digitalization of industrial production systems and their energy demand. Instead of focusing on component development, the Task looked at the overall (solar) system at process temperatures from just above ambient temperature up to approx. 400 °C - 500 °C. Open research questions were the standardization of integration schemes on process level and on supply level and the combination with other efficient heat supply technologies such as combined heat and power plants, heat pumps, or power-to-heat. As a very important aspect, the experiences of numerous solar process heat markets throughout the world were brought together to enable a market-oriented dissemination of existing and new knowledge.

1.2 Project objectives

The integration of solar energy in a hybrid heat supply system is complemented by thermal energy storage technologies including an optimized storage management.

The key objective of Task 64 / IV was to identify, verify, and promote the role of solar heating plants in combination with other heat supply technologies for industrial process heat, such as fossil and non-fossil (biomass and biogas) fuel boilers, combined heat and power plants, heat pumps, or other power-to-heat technologies and thermal energy storage technologies.

2 Approach, method, results and discussion

The Task was organised in five Subtasks. Each Subtask produced a set of deliverables that are briefly described in the following. More details can be found in the published deliverable reports on https://task64.iea-shc.org/publications.

2.1 Subtask A: Integrated energy systems

Lead Country: Germany

Subtask Leader: Dr. Felix Pag, University of Kassel

The main objective of Subtask A was to develop innovative hydraulic schemes for future process heat supply. These schemes deploy different regenerative or highly efficient heating technologies to maximize the final energy and greenhouse gas emission savings compared to monovalent regenerative heating systems.

Specific objectives of Subtask A were to:

- define reference applications for further research in the whole task.
- adapt hydraulic schemes, operational modes, and dimensioning rules of renewable heating technologies when combined to integrated energy systems.
- assess the benefits of integrated energy concepts regarding overall synergies and economical achievable greenhouse gas emission savings.

Deliverables:

A1: Compilation of reference applications for integrated energy systems with solar heating plants incl. representative load profiles

Based on the analysis of more than 800 natural gas consumption load profiles, seven generic reference profiles for industrial heat demand were generated. The profiles reproduce normalized industrial heat demand at three different locations (Bern, Casablanca, Bangkok).

An Excel based tool was developed to generate load profiles at other locations.

A2: General integration concepts and achievable renewable fraction of integrated energy systems

A3: Dimensioning and integration guideline for integrated energy systems

The results of the latter two activities were merged in one report: "Integration Concepts and Design Guidelines".

Task 64/IV revealed that research on combined SHIP and HP systems in industry is mostly limited to the outcomes of the Austrian ENPRO project. For individual design of SHIP plants, the VDI 3988 guideline is widely established and can also be used for the design of the SHIP plant in combined SHIP and HP systems since the solar heat should always be prioritized in combined systems to reduce energy consumption and greenhouse gas emissions to the maximum extent. For the combination of both heat generators and even for individual HPs in industry, an established design guideline is missing so far.

The research done in Task64/IV included a simulation study investigating the performance of combined SHIP and HP systems for applications worldwide. If the free space for installing the collectors is not limited, solar fractions of a design according to the VDI 3988 are ranging between 20 % to 40 % for tempered and a minimum of 50 % for sub-tropical and tropical climates.

2.2 Subtask B: Modularization

Lead Country: Spain

Subtask Leader: Dr. Eduardo Zarza Moya and Dr. Diego Alarcón, CIEMAT - Plataforma Solar de Almería

Objective:

Since the advantages of using modularized components / packages are evident and widely admitted by the entities involved in the design and implementation of SHIP applications, the specific objective of Subtask B was the definition of modularized and "normalized" components/packages for these applications (e.g., components/packages for the balance of plant, solar field, interfaces and hydraulic circuit). The legal requirements currently imposed to some industrial equipment (boilers, heat exchangers, ...) were to be taken into consideration when proposing normalized components/systems.

Deliverables:

B1: Integration schemes and interfaces more commonly used in commercial SHIP applications

The work carried out within this activity has clearly shown the difficulty of identifying a reduced set of integration schemes for implementation in commercial projects. This fact has led to an approach in which after the identification of the most commonly used fluid pairs for both process and solar field, generic BoPs (BoP: balance of plant) and their corresponding analysis have been proposed.

B2: System/component modularization for SHIP applications

The work of ST B concentrated on two activities: 1. developing a guideline for instrumentation and performance assessment of solar fields in SHIP plants with line-focus solar concentrators and 2. the development of a modular and scalable BoP unit for solar process heat applications.

2.3 Subtask C: Simulation and Design Tools

Lead Country: Chile

Subtask Leader: Prof. Dr. José Miguel Cardemil, University of Chile

Objective:

The main objective of Subtask C was to develop simulations and monitoring tools for assessing the potential benefits of integrating Solar Heat into industrial processes, with known sources of uncertainties, taking into consideration economic, social and environmental issues. In addition, the Subtask C was to devote efforts for assessing monitoring strategies that allow improving the performance of actual systems.

Deliverables:

C1: Guidelines for yield assessment, including a checklist for a standardized yield assessment according to the project phase (pre-feasibility, feasibility, proposal, etc.)

This work shows a summary of the results obtained by the comparison campaign of the simulation tools used to evaluate SHIP plants yields. Currently, there is a large number of public and private simulation tools available for the study and evaluation of solar technologies; however, there is a lack of standardized methodologies that collect the vast international experience of the scientific community. These standardized methodologies would reduce inadvertent errors that can significantly impact the performance and design of the schemes. In addition, it was noticed that most of the project developers use their in-house developed tools; however, certain tools have been developed to model specific systems and do not perform appropriately for technologies different from the original.

C2: Guidelines for implementing simulation tools for assessing and monitoring the performance of SHIP systems

The report “Guidelines for simulation tools and monitoring the performance of SHIP systems” encapsulates the main findings from the second stage of Subtask C. Over the span of four years, Subtask C convened 50 participants representing academia, applied research, and project developers across 15 countries. The synthesis of research and firsthand insights from project developers enriches the significance of the analysis presented in this report.

The document presents a comparative summary of reference documents regarding the operation and monitoring of solar thermal plants. Secondly, it indicates key aspects to be considered during the design phase as well as in the operation and maintenance phase, including which variables to measure, where to measure, what sensor to use, etc. Additionally, specific aspects for the main solar process heat technologies are outlined, considering critical components and environmental conditions. Moreover, the report outlines the main topics that should be considered during monitoring and maintenance according to recommendations from companies developing projects for industrial process solar heat and companies monitoring solar systems to optimize their usage. Finally, the document presents the conclusions of the work carried out in Subtask C regarding Best Practices in monitoring and maintenance of SHIP plants.

2.4 Subtask D: Standardization / Certification

Lead Country: Greece

Subtask Leader: Vassiliki Drosou, CRES

Objective:

The main objective of Subtask D was to investigate the standardization and certification area regarding the technology of solar process heat, to support the existing ongoing relevant standardization and certification activities and to suggest and develop new innovative standardization procedures and certification aspects considering the relevant technological developments and legislative requirements.

Unfortunately, due to lack of funding, subtask D had to be cancelled completely before delivering any results.

2.5 Subtask E: Guideline to Market

Lead Country: Germany and Austria (co-chairs)

Subtask Leader: Dr. Peter Nitz, Fraunhofer ISE, Jürgen Fluch and Wolfgang Gruber-Glatzl, AEE INTEC

Objective:

Subtask E aimed at drafting the guidelines of a market approach more prone to be successful among industrial end-users. Closing the circle of strategies tackling technical and non-technical barriers to market penetration, in this subtask Solar Process Heat was to be delivered to industrial end-users as a simple, reliable, innovative, affordable and profitable technological solution for the decarbonization of heating (and cooling) supply to industry.

Deliverables:

E1: Collection of available solar process heat related national and trans-national research and funding programs

In a survey amongst experts involved or connected to Task 64/IV Solar Process Heat, available incentives for SHIP installations and research funding programs from 18 countries (out of 32 countries approached in total) have been collected.

In those countries that show the most advanced SHIP rollout, funding instruments are available. However, the availability of funding instruments alone seems not sufficient for a successful broad SHIP rollout.

Based on the results of the survey, the subsequent analysis of the feedback and discussions in the Subtask, the expert group active in Task 64/IV “Subtask E: Guideline to Market” recommends incentive/funding instruments to support the faster and broader market rollout of SHIP technologies. Based on the feedback of relevant technology suppliers within the Subtask E expert group, direct subsidies on initial investment for SHIP installation (CAPEX) are the preferred option of funding/incentive programs as it is easiest to include in an economic assessment approach, for communication with end users and by this, to support actual implementation including financing. But as diverse SHIP plants are, as important are specific solutions for all relevant stakeholders along the different project phases including the industrial end-users, the technology suppliers but also plant operators and investors.

E2: Update on technology costs, statistics and cost reduction trends, including suitable energy cost evolution perspectives and promoting the use of LCOH as benchmark for the comparison of innovative heating/cooling production systems

E3: New trends on financing schemes and business models to SHIP and collection of available SHIP financing possibilities

The merged report “Update on SHIP technology costs and SHIP business and financing models” gives an update on technology costs, statistics, and cost reduction trends, including suitable energy cost evolution perspectives and promoting the use of LCOH as benchmark for the comparison of innovative heating/cooling production systems and describes new trends on financing schemes and business models for SHIP and a collection of available SHIP financing possibilities.

Additional activity: Calculation method for the conversion of aperture area into thermal power for tracked concentrating solar thermal systems for statistical purposes

Energy statistics usually include data on the amount of solar thermal energy installed in terms of thermal power (kW_{th}). While solar thermal installations often are only characterized by the installed collector area (m²). To address this inconsistency between data, a simple conversion factor is needed to convert the installed area (m²) into the approximate corresponding installed thermal power (kW_{th}). Such a conversion factor exists for stationary solar thermal collectors but has yet to be established for tracked concentrating collectors. This paper details a conversion factor for tracked concentrating solar thermal collectors developed in the IEA SHC Task 64 / IEA SolarPACES Task IV on Solar Process Heat and the underlying reasoning.

3 Conclusions and Outlook

This chapter is adapted from the Task’s position paper (see https://task64.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task64-Technology-Position-Paper-SHIP-2024-01.pdf), that 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 and decision-makers as well as influencers and aims to present high-level information as a basis for the uptake and further development of SHIP.

3.1 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 Task.

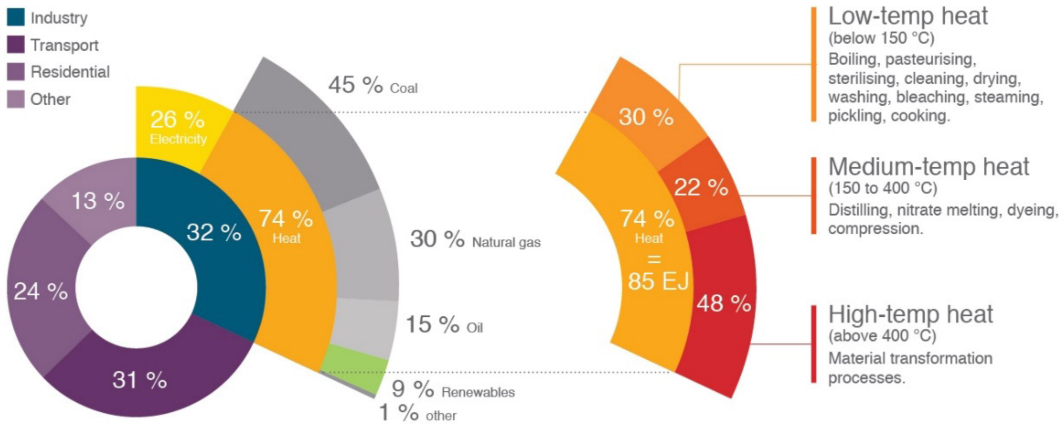

Figure 1: Total final energy demand, share of heat demand, temperature levels, and current energy carriers for industry worldwide.[1]

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. With a smart concept design including 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 be easily scaled to the end-users' 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 currently 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 that meets a huge market potential.

1 Source: https://www.solar-payback.com/wp-content/uploads/photo-gallery/.original/Enourmous_Global_Heat_Demand_in_Industry_EN.jpg?bwg=1587229039
2 IRENA (2020) Renewable Power Generation Costs in 2020

3.2 Current Status

SHIP technologies are market-ready and available for the 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 MW_{th})[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.

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://solarthermal-world.org/news/high-level-of-dynamism-on-the-ship-world-market-in-2022/

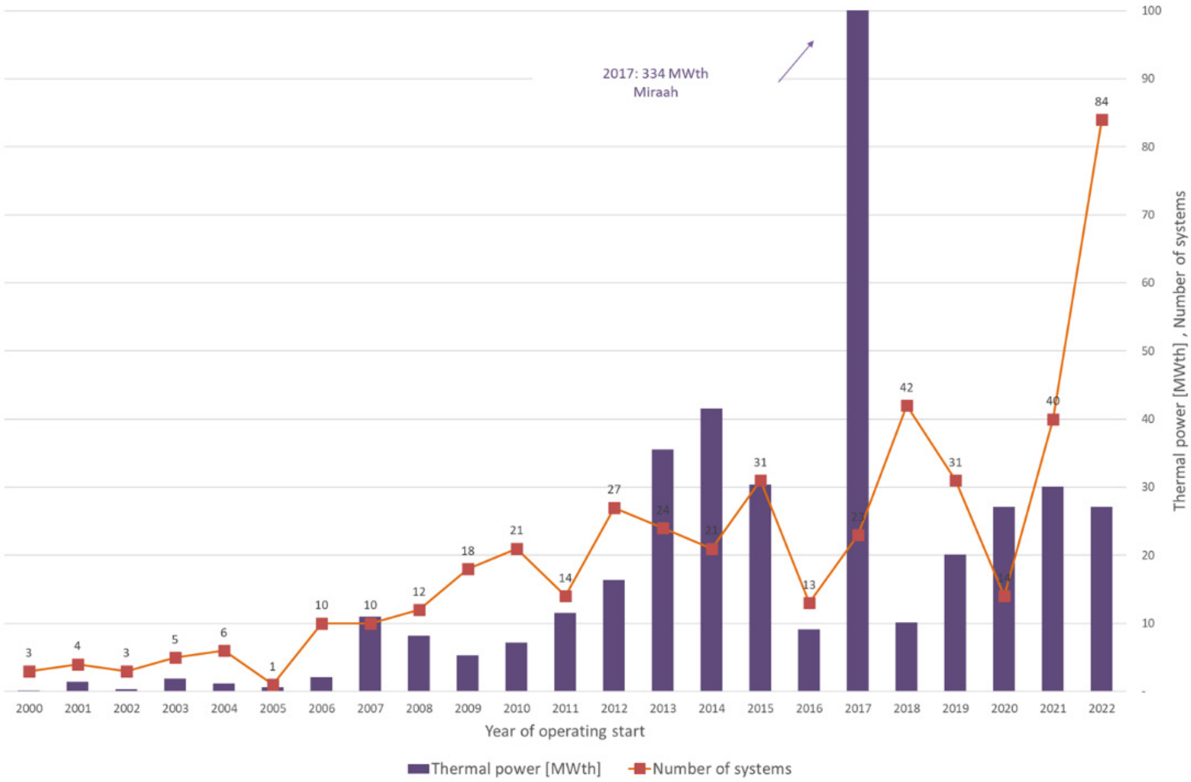

Figure 2: Documented annual installation of SHIP systems from 2000 to 2022 on the www.ship-plants.info database.

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. 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.

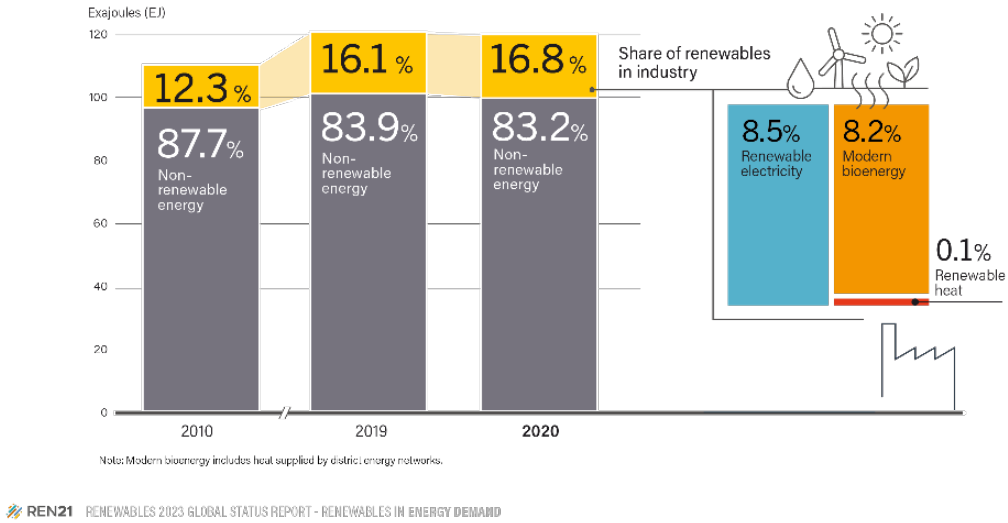

Figure 3: Renewable share of total final energy consumption in Industry.[5]

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 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 it being 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.

3.3 Potential

3.3.1. 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

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

[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)

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.

3.3.2. 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 of 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 by 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 a base technology for the industrial heat transition and help companies be more independent from other heat supply costs.

3.3.3. 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 as 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-

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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

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

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.

3.4 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.

Table 1: Challenges and actions identified to strengthen the market uptake of SHIP.

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**:** • 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 affordability 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).	Policy makers, politics
Public awareness	**Raise awareness on the role of SHIP** in CO_2-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**. **Mandatory 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

4 National and international cooperation

The nature of an IEA TCP is to have many international partners collaborate and join forces. Around 50 people participated in Task 64/IV, coming from 11 countries that are members of SHC or of SolarPACES.

Table 2: Participating Countries.

	Research Institutes	Universities	Companies	Consultants
Austria	2	1		
Chile	1	1		
China			1	
Denmark		1	2	
France	1		2	
Germany	2	1	1	2
Spain	2	3	2	
Switzerland		1		
Turkey		1		
United Kingdom		1	1	
USA	1			1

5 Publications and other communications

All project results are available on the task website https://task64.iea-shc.org.

Table 3: Journal Articles, Conference Papers, etc.

Author(s)	Title	Publication / Conference	Bibliographic Reference
Dirk Krüger, Bärbel Epp, Tobias Hirsch, Martina Neises-von Puttkamer	Developments in Solar Heat from Concentrating Solar Systems	SolarPACES Conference	2020
Bärbel Epp	Project sponsors need to offer banks sufficient securities and guarantees	solarthermalworld.org	2020

Author(s)	Title	Publication / Conference	Bibliographic Reference
Mateo Jesper, Florian Schlosser, Felix Pag, Timothy Gordon Walmsley, Bastian Schmitt, Klaus Vajen	Large-scale heat pumps: Uptake and performance modelling of market-available devices	Renewable and Sustainable Energy Reviews	Vol 137, 2021, 110646, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2020.110646 https://www.sciencedirect.com/science/article/pii/S1364032120309308
Bärbel Epp	Standardised yield assessments for industrial solar heat plants	solarthermalworld.org	2021
Jose Miguel Cardemil	IEA SHC Task64/SolarPACES Task IV – SubTask C: Assessment of uncertainties in simulation tools	SWC2021	2021
Mateo Jesper, Felix Pag, Klaus Vajen, Ulrike Jordan	Annual Industrial and Commercial Heat Load Profiles: Modeling Based on k-Means Clustering and Regression Analysis	Energy Conversion and Management, Volume 10, June 2021, 100085	https://doi.org/10.1016/j.ecmx.2021.100085
Jakob Jensen	Large-Scale SHIP Installations Without Risks & Investments	UNIDO (webinar)	19.04.2021
Jakob Jensen	Evaluation of high-temperature solar thermal opportunities in the Netherlands	TNO (advising the Dutch government on subsidy schemes needed to support solar thermal)	20.05.2021
Jakob Jensen	Presentation of the market potential for industrial process heat <200C, Heliac solution, and competing solutions for this temperature range	Energistyrelsens fjernvarmegruppe under 'Center for Global Rådgivning	27.08.2021
Jakob Jensen	Presentation of the market potential for industrial process heat <200C, Heliac solution, and competing solutions for this temperature range	Dansk Industri (conference: "Sol Over Danmark")	31.08.2021
Cardemil, J.M.; Calderón-Vásquez, I.; Pino, A.; Starke, A.; Wolde, I.; Felbol, C.; Lemos, L.F.L.; Bonini, V.; Arias, I.; Iñigo-Labairu, J.; Dersch, J.; Escobar, R.	Assessing the Uncertainties of Simulation Approaches for Solar Thermal Systems Coupled to Industrial Processes	Energies 2022, 15, 3333	https://doi.org/10.3390/en15093333
F. Pag	CO2-freie solare Prozesswärme in der Oberflächentechnik,	43. Ulmer Gespräch - Forum für Oberflächentechnik, Ulm	05.05.2022

Author(s)	Title	Publication / Conference	Bibliographic Reference
Pag F., Jesper M., Kusyy O., Vajen K., Jordan U.	Deckungsraten solarer Prozesswärmeanlagen unter Berücksichtigung des Lastprofils und vorhandener Dachflächen	Proc. 32. Symposium Solarthermie, Bad Staffelstein	03.05.2022
Jesper M., Pag F., Vajen K., Jordan U.:	Can Electricity Load Profiles Be Used to Increase the Accuracy of Heat Load Profile Predictions in Industry?,	Proc. International Sustainable Energy Conference, Graz, Austria	06.04.2022
Pag F., Jesper M., Kusyy O., Vajen K., Jordan U.:	Solar Fractions for Solar Process Heat Plants Taking into Account Load Profile and Available Roof Area,	Proc. International Sustainable Energy Conference, Graz, Austria	06.04.2022
Häberle, Andreas	Keynote lecture “Solar Heat for Industrial Processes”	EuroSun 2022, Kassel	September 2022
Jesper M., Pag F., Vajen K., Jordan U. (2022):	Heat Load Profiles in Industry and the Tertiary Sector: Correlation with Electricity Consumption and Ex Post Modeling,	Sustainability, Vol. 14, Iss. 7, p. 4033	doi:10.3390/su14074033
Pag F.	How the available roof area and the heat load profile influence the potential of solar heat in industry?,	Wind and Solar Energy Week, Kassel, Germany	24.03.2022
Jesper M., Pag F., Fluch J., Gruber-Glatzl W., Vajen K., Jordan U.:	Reference Applications for Renewable Heating Systems in Industry and Commerce,	Solar World Congress, Online	25.10.2021
Jesper M., Pag F., Vajen K., Jordan U.:	Hybrid Solar Thermal and Heat Pump Systems in Industry: Model Based Development of Globally Applicable Design Guidelines	Solar Energy Advances,	https://doi.org/10.1016/j.seja.2023.100034., 2023
M. Jesper, F. Pag, K. Vajen, U. Jordan	Auswirkungen der Energiepreisinflation auf die wirtschaftliche Bewertung industrieller Abwärme-Großwärmepumpen	Symposium Solarthermie und innovative Wärmeversorgungssysteme	2023
F. Pag, K. Vajen	Wie können Solarthermie und BHKW für industrielle Anwendungen möglichst effizient kombiniert werden?	Symposium Solarthermie und innovative Wärmeversorgungssysteme	2023
W. Gruber-Glatzl, A. Häberle, P. Nitz, F. Pag, J. Fluch	Solare Prozesswärme als Schlüsseltechnologie der industriellen Dekarbonisierung –Positionspapier IEA SHC Task 64	Symposium Solarthermie und innovative Wärmeversorgungssysteme	2023

Author(s)	Title	Publication / Conference	Bibliographic Reference
Y. Louvet, F. Pag, D. Ritter, C. Schmelzer, K. Vajen	Häufige, aber vermeidbare Fehler bei Planung, Installation und Betrieb solarer Prozesswärmeanlagen	Symposium Solarthermie und innovative Wärmeversorgungssysteme	2023
F. Pag, Y. Louvet	Kombination solarthermischer Anlagen mit KWK-Anlagen im industriellen Prozesswärmebereich	KWK-Jahreskongress	2022
M. Jesper	Großwärmepumpen und Solarthermie in der Oberflächentechnik	12. Südwestfälischer Oberflächentag	2023
Häberle, Andreas	Keynote lecture “Solar Heat for Industrial Processes”	ISEC 2024, Graz	April 2024